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The Zodiac

By STEPHEN A. and MARGARET L. IONIDES
Authors of "Stars and Men"

The Ram, the Bull, the Heavenly Twins
And next the Crab, the Lion shines,
The Virgin and the Scales,
The Scorpion, Archer and Sea-Goat,
The Man who held the Watering Pot
And Fishes with glittering tails.

ISAAC WATTS.

The Ram, the Bull . . . The animals of the Zodiac were active beasts of burden once, and still carry on their backs the significance of our daily lives. But art, astrology, and myth together have shown them as mere fabulous monsters grinning from our walls. Zodiacs appear everywhere; on sundials, in universities, on sandwich plates and elevator doors. Decoration? Certainly. But decoration that could have meaning behind the symbols, and purpose behind all the forms.

Artistic indifference is partly to blame for our ignorance. Why bother about symbolism? Yet we all hunt for reasons. In an agricultural college a young girl was heard explaining to her family: "Now the ram and the bull are for Animal Husbandry, the fishes for Ichthyology, and the woman—I forget—oh yes, she represents the department of Home Economics."

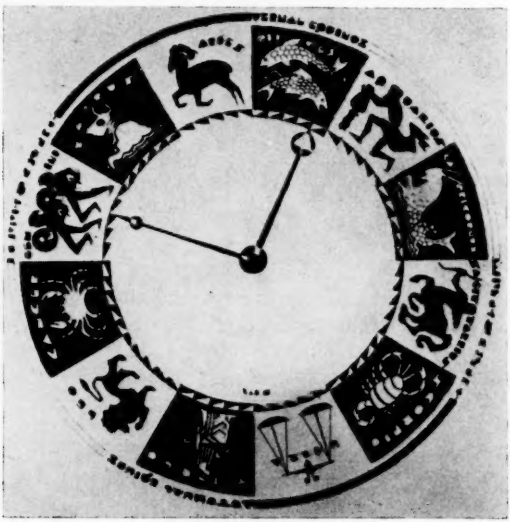
Perhaps that girl was not entirely wrong—and her explanation, ingenious as it was, has its merits. The animals in the Zodiac do in their way represent an agricultural college—if a college means a stimulus to people who want to learn; generations far older than hers studied them; and the pictures have a longer history than any her small college could put on its written records.

The symbols of the Zodiac go back to a time before writing was known; a time when pictures represented thoughts; the artist was the author. He impressed his ideas on clay or chiselled them deeply into rock.

Hundreds of years later, in Babylon, about 1200 B.C. the surveyors used to set up "boundary stones" much as we mark corners; complete with dates and pictures and a certain ritual inscription handed down to them by their forefathers. Some of these designs are astronomical. Of course, the heavens were their calendar, their encyclopedia, and their religion. No artist then would dare to distort the signs of the sky.

One of the favorite pictures represents a young crescent moon, with

the horns pointing straight upwards, and near by it are two stars. Now the moon in that position occurs only near the time of the spring equinox—and we know that the Hebrews began their spring month from its appearance. But what about the two stars? There are none nearby the young moon at that time, nor were there any in 1200 B.C. But in 5,000



Design by Wm. Traher

FIGURE 1

THE ZODIAC ARRANGED AS A CLOCK
(From "Stars and Men")

B.C. the spring equinox was in the constellation of Gemini—the Twins. In those far off days, the stars of Castor and Pollux shone close to the crescent spring moon. Tradition had persisted for 3,800 years; and the Babylonians were copying the old symbol of their ancestors and placing it upon their freshly made boundary stones.

There were other astronomical signs on these boundary stones too. We see there the goat with the fish's tail, which we now call Capricornus —the Horned Goat of the Sea-Goat; and there is the Winged Horse which was to become the symbol of poetry in Greek legend, and to be impressed on coins as a sign that they were made in the city of Corinth. Such creatures as these are the stuff from which myth and legend are made.

But just what do we mean by "myth"? Is it only the product of outrageous fancy, which combines men and horses, goats and fishes, lions and women into creatures half one and half the other, or is there some

reason behind these weird combinations, not a half-seen being in the twilight—as I myself have seen an elk with antelope horns—but a real reason for combinations and legends? Students of myths divide them into three classes. The first, and smallest, is a mere product of fancy—possibly pure invention to justify some folly—much as the aggressor nations today use myth as a basis for their wanton acts. Then there is an intermediate classification—truth told fancifully and embellished in the telling until fact and fancy are so mixed that it is almost impossible to dis-

FIGURE 2
BABYLONIAN BOUNDARY STONE
(From "Mesopotamian Archaeology" by S. P. Handcock.
Reproduced by permission of G. P. Putnam's Sons.)

tinguish between them. Into this category fall many so-called superstitions—bad luck to thirteen at a table, derived from the thirteen at the Last Supper, becomes bad luck to thirteen of anything; and puts a scourge on Friday the thirteenth. Finally there are the myths, which not only tell the truth in a fanciful manner—as do many children's stories—but really describe the unfamiliar in familiar terms.

Mythology tells us that Jupiter hurled his thunder from High Olympus. This is pretty and fanciful; but it is certainly a graphic means of saying that thunder clouds—such as are described by Richard Halibur-

ton, in his "Glorious Adventure,"—frequented the mountain tops. As such it is a good meteorological observation.

Mythology also tells us that Jason and his Argonauts set forth to find the Golden Fleece. Many hundreds of years later Spanish noblemen founded the order of Chivalry of the Golden Fleece—one of the highest orders in Europe. What was this Golden Fleece Jason sought? Almost up to the beginning of this century questioners might have asked in vain, but today the fleece of sheep (often made into carpets) is used to catch the gold from crushed ore or from placer deposits of the precious metal. And who is there to say that the report of a rich placer mine had not penetrated to Athens? The gold taken from Mycenae and Tiryns today fills the great room in the Athens Museum. Gold in Crete and Egypt and Ur was so common that silver outranked it for value. The story of the Golden Fleece comes from the times when the first Achaeans stormed like savages into the heart of the Peloponnesus. Surely they must have been astounded by the rumors of so much precious metal. May it not really have been a gold rush—like California's, like the Klondike's—which started Jason and the good ship Argo?

Perhaps we can go yet further. If some myths describe fact in a fanciful manner, some others may describe a truth which would not make sense to its listeners if told in any other way. Horses were not known in the early days of Egypt or Babylon. How could a Hittite describe the speed of a horse to a person who had never seen one? To say that it was swift carried little conviction. But to draw it with wings! Ah, that made sense.

The pictures of the Zodiac are all attempts to make sense out of the sky, to link the unfamiliar with the familiar. A very clever piece of research has traced the namers of all the anciently known constellations to a group of people who lived between 2,700 and 2,000 B.C. But the constellations of the Zodiac may have been named earlier still.

Technically, the Zodiac is the belt 16 degrees wide, 8 degrees on either side of the ecliptic (the Sun's apparent path) within which are found at all times, the Sun, the Moon, every planet except Pluto, and most of the charted comets. It thus constitutes a most important part of the sky.

The constellations of the Zodiac are the groups of stars, through which the ecliptic passes. Today we recognize twelve such constellations, though at the beginning—probably only four had names, later six, then eleven, and finally our twelve.

Very early in the history of man, when he first began to sow and reap, he found the need of a calendar. Warm days are not necessarily the harbingers of spring or summer, nor cold of winter. Animals have apparently some sixth sense, but man needs to forecast the seasons, and prepare for them. What was a more logical way of making a calendar, than by drawing familiar pictures,—the bull, the lion, the scorpion, and the water bearer? The bull ploughed up the earth for the spring crops; the lion personified the heat of the summer; the scorpion curled his

claws around the autumnal equinox (It's a warm day that brings forth the adder) and the man with his watering pot tipped it until the rain fell out upon the earth.

The history of the Zodiac has never been static. If it had ever ceased to grow it would have died, and filled an unhonored grave for lo these many centuries. Once invented it has been a constant joy for astronomers and artists. But the common-or-garden rams and bulls among humans have despised it as something from ancient days which they can not understand.

FIGURE 3
COAT OF ARMS OF GREAT BRITAIN

Astronomers soon needed more than the original four divisions; but the four remain in our seasons. To mark them four royal stars were named. Aldebaran for spring, Regulus for summer, Antares for autumn, and Fomalhaut for winter. These four symbols were carried by the children of Israel in their great migration through the wilderness. Judah had a lion, Reuben a man and a river, Ephraim a bull, and Dan an eagle with a serpent.

Just what happened next we do not know. Probably the history of the Zodiac followed the same general pattern as many ideas. It started simple; then additions were made at various times and places, some with knowledge and some without, until it grew so complicated that the originals were hard to distinguish in the general conglomeration.

The effect of one such mixture is well known. The Babylonians considered that the mid-summer Sun was the pride and glory of the year, so the animals were always shown approaching or backing away from it, as if the Sun on the 21st of June was the King day of the year. The two animals at the top were the bull and the lion. The lion was quite a

fair portrait of the animal, but the bull was shown so strictly in profile that he seemed to have only one horn. There they stood, facing each other, two ferocious monsters; and later artists, copying like slaves, made a lion and a unicorn fighting for a crown,—and there they stand on the British coat of arms today.

To develop all the changes would be a tedious task and contain more than its share of surmise. The adoption of the number "twelve" is natural. We have twelve inches to the foot, twice "twelve" hours to the day. We have thirty times "twelve" degrees in a circle—and we buy our buns by the dozens, our other commodities by the gross (12×12) and the great gross ($12 \times 12 \times 12$). The months are, of course, derived from the twelve signs of the Zodiac.

For a while there were twelve months but only eleven signs. Scorpio is a large and prominent constellation and Libra a small inconspicuous group of stars, so the great claws of the crooked saurus covered two whole months. But in Greek times the name of the "Balances"—Libra, was imported from the Hindus—a fit designation for the time of year when the days and the nights are equal. An artist who wishes to prove his profound and unqualified ignorance has only to draw these scales with unbalanced pans, and he will accomplish his purpose exceedingly well.

The names of the constellations may be divided into three classes. There are, of course, some constellations which really resemble their names. The Twins, for example, and the Scorpion. Castor and Pollux (the names of stars, as differentiated from the names of constellations, have an obscure mythological origin) are a brilliant pair. They have been called "Twins" in almost every language, though sometimes they were twin peacocks, and sometimes twin goats, but always twins, except indeed among the Romans who couldn't get the idea out of their heads that twins founded cities as a matter of course, and so sometimes represented this constellation by a pile of bricks instead. But Gemini is obvious. Similarly anyone who has seen Scorpio's stars crossing the southern sky about 8:00 P.M. in the month of August can see plainly the head and the long curling tail. Very little imagination is necessary to see the "Scorpion."

Of the remaining ten constellations not one is named for the picture in the stars themselves. Even if one knows the names, and what they are supposed to represent, he will have a hard time fitting the picture to the stars. Yet this process is just what early artists tried. The animals or persons or artifacts lent their names to the constellations because they had some precise significance. The figures were drawn later.

> Every little figure has a meaning all its own.
> Every thought and feeling by some posture can be shown.

These meanings are the important things for us to remember.

Perhaps we had better list them in their present order:

The Ram, leader of the flock, heralds the lambing season. Because of their vocation, shepherds were early observers of the skies. David had been a shepherd, and he showed more knowledge of the skies than any other Israelite of his time.

The Bull was the great leader of the skies during the historic temple building days of Babylon and Egypt. In those times, at the spring equinox, the Sun passed from the southern to the northern hemisphere in this constellation. The Bull was represented as opening the furrow of the year, and his worship formed a religion which passed over the greater part of the known world.

Next come the Twins, and then the Crab, whose name is the most typical example of the method of selection of animals. It is not reasonable to suppose that any crab could have been a hero—worthy to have his name inscribed in the skies. Nor does the ferocious little animal seem sufficiently dignified to merit a place in the skies; and certainly the stars look just as much like a giraffe or a snail. Yet there he is—utterly foolish, apparently, and nonsensical. Why a crab?

The reason is very simple. At midsummer the Sun has reached the farthest point northward in its annual journey; and then for a few days it seems to travel sideways before starting southward again. And the only animal which moves neither forward nor back, but scuttles to the side, is a crab. To him then fell the unexpected honor!

There is a mystery about the Lion, a riddle which has never been solved. We know that the Egyptians considered this beast to be typical of summer heat. We know they said that in mid-summer the Lion came down to the Nile to drink. But how these legends developed no one has known. Only the riddle remains. Half buried in sand, the Lion with the next constellation, the Virgin, forms the Sphinx.

The Virgin is goddess of autumn and the prophet of far-off spring. In mythology she shone as the goddess Ishtar, who in the fall went to Hades after her husband; dwelt there with him six months, and, in order that winter might end, brought him back to the surface of the earth again. When he came the trees grew green and, in token of his everlasting life, the lads and lasses of 2,000 B.C. decked a pole with gay colors and danced around it on the grass.

But in the autumn, after the Virgin has descended to Hades, comes the time of the autumnal equinox—the time when the days and the nights are equal—and how could it be symbolized more perfectly than by a balance with poised scales—the same emblem which was used for Roman courts of justice? Hence, Libra, the Balance.

Of Scorpio we have already spoken. It is easy to recognize in the skies at midsummer; but when it is rising and setting with the Sun the darkness of winter is at hand. Symbolically the scorpion, like its cousin the dragon, and its great uncle the crocodile, and all its sisters and its cousins (which it reckons up by dozens) of the saurus tribe, was a sworn enemy of light. It is time to prepare for winter.

Sagittarius, the Archer, suggests this very preparation. When the Sun is in this constellation all game animals are at their prime. He is a hunter, originally probably a man on horseback, later a combination, half horse, half man—and again we have an example of bad imitation, and imperfect craftsmanship—the same kind of fault which created the unicorn. At the time when he is rising and setting with the Sun, another mighty hunter, Orion, is striding through the evening sky. Orion was on foot, and slew his game with a two-edged sword. But the archer rode on horseback, and shot with bow and arrow. Surely such a man as this would know enough to look where he was shooting. But for some inexplicable reason modern Zodiacs often show him glancing back over his shoulder as if in fear, while he points his arrow at some unseen quarry ahead.

And after him comes another mysterious animal. Capricornus, the Sea-Goat, has the body of a goat and the tail of a fish—and what should such a mer-goat be doing in the Zodiac? The Sun, as it enters Capricornus, is at its farthest point south, and is ready to start climbing back northward again. He needs all possible help—so we give this group of stars the climbingest of all animals to help him on his way. But the Sun has been at the very lowest point that we know—obviously sea level. Here, as at the top, he must travel sideways for a short distance; so the goat is equipped with a fish's tail, then the Sun may swim for a while before he starts to climb.

The artist who shows the goat on a mountain top is akin to the artist of the unbalanced scales.

The rains come. We students of the heavens know that they will come, and in our heavenly calendar we tell this to all others whose understanding is not the equal of ours; so we label this constellation "Aquarius," the Waterer, the Man with the Watering Pot, who tips his jug so far that the waters of the heavens come out and fall on earth. He lives in the sea of the skies, surrounded by marine animals. On some good-natured Zodiacs he is carrying an appropriate towel over his arm. And on one, a very religious document of the tenth century A.D., he turns up as John the Baptist.

From the rains we must recover; and the traditional bearers of life in water are the fishes, Pisces—always shown double, probably because in the month of February extra days were added, and sometimes in the ancient mix-up of calendars, extra months as well. The fishes survived marine existence, and brought new life to the land.

These are the constellations of the Zodiac—the name, given by Aristotle, means only "the belt of animals." Through thousands of years the creatures have continued without subsidy or sponsorship of any visible kind. There is little else in this changeable world of ours with such a record. The reason is very simple. The Zodiac combines utility with beauty and has tales to tell to anyone who will listen.

The arrangement of the order of the constellations is likewise not a

matter of complete indifference. First of all they must be arranged counterclockwise, or "widdershins" to indicate the direction of the path of the Sun during the year.

Now it has been the custom for many years to put the north of a map at the top. If we vary from such a general rule, we mark the difference with an arrow. The northerly point of the Zodiac is the first point of Cancer. This, therefore, should be at the top of the map. Then the system is set.

When the Zodiac is on the ground the Ram must be at the East, the Crab to the North, the Scales to the West, and Capricorn, the Sea-Goat, which is the most southerly of the Zodiac constellations to the South. If the pictures are in a book, or set upon a wall, the Ram is to the right, Crab at the top, Scales to the left, and Sea-Goat at the bottom. This is the natural and understandable order, yet we have seen them reversed, set top to bottom, quite indifferently. The result is about as intelligible as if we should suddenly begin to letter an inscription Chinese fashion, and expect everyone to read it.

Certain causes, of course, justify variations. If the Zodiac is used as a clock face, the Ram as the starting point, must be on top. Everyone who has ever fired a rifle at a target knows where "Three o'clock" is, and to put "twelve" there would be straining at a crab and swallowing a lion.

So far we have discussed nothing but the "Constellations" of the Zodiac, with hardly a mention of the "Signs," yet the expression "*Signs* of the Zodiac" is common, whereas the "*Constellations* of the Zodiac" are very rarely heard from. We must then develop the relationship.

In the beginning they were the same. Everyone thought that the "fixed stars" of the heavens were eternally changeless. But in 140 B.C. Hipparchus of Samos, while making new star maps and poring over old ones, discovered that the stars had moved. The movement was very slight. It is hardly perceptible during the life time of one man. Nevertheless the stars do appear to move.

Actually (in this connection as in many others) it is the Earth which moves. Every twenty-six thousand years the pole of the Earth completes a little wobble—much like the wobble of a top when it is running down. You need not assume from this that the Earth needs winding up. Precession is a constant motion, but a disturbing and interesting one, because over aeons it is sufficient to make the stars appear in different places in the sky.

However, Hipparchus was considerably worried over his momentous discovery. If the fixed stars could move—was there nothing changeless in the universe? But like most geographers he set to work making a map of the heavens just as he saw them. At that time the place where the Sun's path crossed the equator was the First Point of Aries.

The First Point of the Constellation Aries has slid far away by now; and the intersection of the ecliptic and the equator has passed through

Pisces and is almost in Aquarius. But the *sign for the intersection remains the same.*

In other words, since the time of Hipparchus the *Signs* of the Zodiac have been absolutely fixed divisions. They pay no attention to the Constellations, which were once their inseparable companions. They are the die-hard tories of the old tradition, clinging to the past, denying the natural change of the world. In this case the past to which they cling has ceased to exist since 140 B.C. But for all that this artificial system is an extremely useful device.

In the first place the constellations are only groups of stars, therefore their size varies considerably. The Signs have the same names, and the same symbols, but (like any manufactured object) they are perfectly regular. Their whole importance lies in their "First Points." The rest is merely filler in. Always the First Point of the sign corresponds to the equinox or the solstice as the case may be. The date when the Sun enters the First Point is marked in our almanacs. Convenient as this division is, in the hands of the ignorant it leads to confusion. Almanac makers are apt to ascribe one sign to one month. The First Point of Aries must be in March; therefore they calmly chalk up March with a ram's horns; though during only ten days of March can the Sun be coincident with that sign.

The signs of the Zodiac are also used by astrologers for their prophecies. In the beginning astronomy and astrology were one science—the study of the heavens and the effect they had upon mankind in general, or the country in particular. No one thought of applying the positions of stars or planets to the future of individuals. But when men began making money out of telling fortunes, the two groups split. Then these newcomers took the old name "Astrology," and the followers of the old science had to adopt a new title. They called themselves astronomers, or star-arrangers.

The astrologers adopted the constellations of the Zodiac wholesale and made them a leading line in their business; but instead of the pictures, they preferred the shorthand "Symbols," and have continued to plaster them all over the place ever since. Every reader of astrological periodicals is familiar with the sight; so familiar that many people, including some good astronomers, seem to have forgotten that the good scientists, rather than the astrologers, gave the names to the constellations.

And don't forget, if ever you have your fortune told by the stars, that the prophets are using the *Signs,* not the stars themselves. And when they say you were born under Aries, they mean that you would have been born under the stars of the Ram if you hadn't been born when you were, but only if you had been born when you weren't—unless of course you date from Hipparchus—in which case we wish you many happy returns of your two-thousand and eighty-first birthday.

The shorthand notations of the signs—and they are also used for the constellations—are so convenient that they are to be found in many per-

fectly respectable and extremely sober volumes on astronomy; the *Nautical Almanac,* and the *American Ephemeris*—to quote but two. These "symbols" have meanings just as definite as the constellations to which they refer, and should be written with equal care to preserve their connections.

The symbol for the Ram is ♈ and should show some suggestion of the curling horns of a wild sheep. Similarly the Bull ♉ should be the abstract skull of its namesake. This is a very ancient sign, frequently used in the early days of Egypt. The sign for the Twins ♊ certainly suggests twinness, and so on throughout the list, though a few are probably the initials of some ancient word for the sign. These and the rest of their kind are available today in both United States and England for use with linotype machines. The meanings are interesting, but after all only secondary and there is little—if any—reason for the use of marked variation any more than for marked variation in everyday letters. First of all they should be clear and distinct.

The Zodiac—both constellations and signs—was used by astronomers up to the time of Copernicus. Throughout the years when men believed that the earth was the center of the universe, and that the Sun, Moon, planets, and stars revolved around the earth, "ecliptical astronomy" was of great importance, and almost all celestial measurements were made from the sun's path, and from a line at right angles to it. Today, we measure largely from the equator; the ecliptic becomes in astronomy only an added complication whose use is practically limited to the manufacture of planetariums.

The development of the Zodiac, like most other attributes of the human race, has gone in waves; but the waves have been distinctly progressive. The setbacks have come from ignorance or indifference or both; and these failings persist today. We are now going to show some of the horrible examples that follow from these failings, and we are going to choose for our exemplification the almanacs issued by one of the substantial and ordinarily progressive corporations of this country. We shall leave it anonymous, as it needs no further advertising from us. Its goods speak for themselves and the company has been more than usually successful in persuading its customers to urge their friends to join them in the use of its wares.

Every year this company prints and distributes freely copies of its almanac, in which the figures or the symbols of the Zodiac appear on the cover and elsewhere on the pages. In the 1937 edition among the errors they showed their disdain of Latin by portraying "Aquarius" as a lady. They cut her hair in the next number.

In 1938 they had "Libra" with the scales carefully arranged "out of balance" to announce to the world that they are disobeying the equal laws of Roman Justice, and issuing propaganda. Nor, apparently, might the world be allowed to know that the days and nights were equal at the time of the autumnal equinox.

It looks as if someone must have criticized them for the figures they used, so in 1939 they decided that they would not take up arms against a sea of troubles, but—rather than bear the ills they had—they would fly to others that they knew not of. The simple figures were replaced by the more obscure symbols, but the map was turned upside down, and the northern constellations appeared in the south! On the inside pages were slavishly made copies of the drawings for the Zodiac—all excellent in the original, undoubtedly—just as the bull was a good bull before he became a unicorn. In this case the Archer "Sagittarius" is looking to the left while pointing his arrow to the right. Probably the original artist was lampooning some well known character of his time—a man perhaps who had brought off some great accomplishment while pretending to do something entirely different; or perhaps he had shot someone by mistake; or possibly he was only born with a squint—and the artist, or more likely the cartoonist, was holding him up to ridicule.

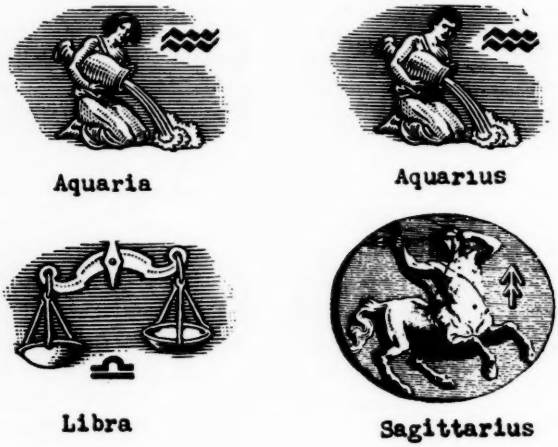


FIGURE 4

But why copy slavishly? It is much more fun to devise one's own Zodiacs—and freedom comes from knowledge, in this case as in many others. The variations in each design are as many as the variations of the human face; but there are limits. Except among the complete abstractionists one does not draw eyes like a violet, lips like a cherry, and necks like a swan—and the number of each is fairly definitely set. Yet if one had only read about the human face in poetry, and never seen it—such would be the picture. The company we refer to had—perhaps—only read about Zodiacs.

The Zodiac has had five thousand useful years to its credit. Only

when we turn its beasts of burden into fabulous monsters will it cease to live. With its constellations and signs; science and myth; beasts and super-beasts, it forms part of the texture from which our civilization grows.

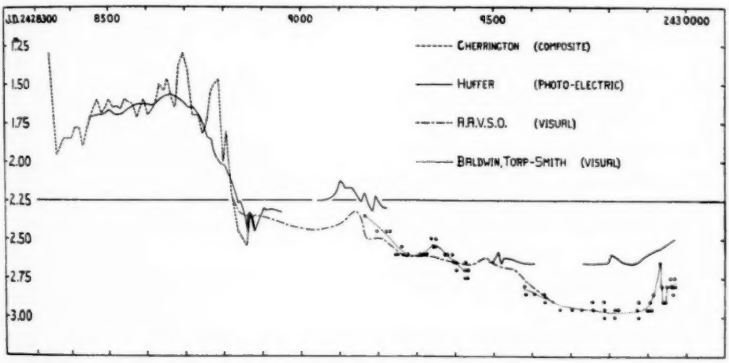
379 Marion Street, Denver, Colorado.

Light Curves of Gamma Cassiopeiae

By RALPH B. BALDWIN and ROBERT TORP-SMITH

In the middle of 1936 the bright Be star, γ Cassiopeiae, caused a furor among workers in the field of variable stars by becoming, without warning, considerably more brilliant. Had the star been a late type M, N, R, or S star, such a performance might have been considered normal. In this case, however, an early type star, class Bope, began to vary after having been thought constant for decades.

Without exception, no other Be star has been observed to pass through such magnitude changes as has γ Cassiopeiae during the last four and one half years. In only one or two cases are Be stars suspected of being intrinsic variables and there the range is confined to about 0.1 magnitude.



Light Curves of γ Cassiopeiae

Numerous observers all over the world have kept the star under observation. Cherrington[1] compiled a light curve from 312 individual observations covering the brightest portion of the light changes. It is, in general, similar to, but brighter than the corresponding part of the A.A.V.S.O. curve.[2] Cherrington has analyzed the two curves thoroughly, and as his curve covers a longer period of time than the A.A.V.S.O. curve, it is reproduced in the figure. The first point on Cherrington's curve is a mean of two magnitude determinations from photographic

plates exposed for other purposes at Case School of Applied Sciences. The exposures were made before the announcement of the brightness increase.

Huffer's photo-electric light curve[3] is also shown in the figure. It is not a continuous record, but in the main agrees well with the other curves.

Observations forming the A.A.V.S.O. light curve after J.D. 2428820 (October 13, 1937) were grouped into ten point means and the plotted A.A.V.S.O. curve passed through these points. There are definite systematic differences between this and the photo-electric light curve which are correlated with temperature changes,[4] *i.e.,* when the star is hot, the photo-electric magnitudes are lower (brighter) relative to the visual magnitudes.

The fourth set of observations plotted is that of the authors, made at Dearborn Observatory by visual comparison with β, δ, and ϵ Cassiopeiae, magnitudes 2.42, 2.80, and 3.44 respectively. δ Cassiopeiae may be slightly variable, but the range is small, and the magnitude has been considered as constant throughout the series of estimates. An attempt to eliminate as far as possible the magnitude error caused by position angle has been made by taking direct estimates of magnitude and then "reversing the observer" for a second estimate.

Our light curve is in excellent agreement with that of the A.A.V.S.O. The brightness of γ Cassiopeiae has been nearly constant at about 2.95 for nearly a year. However, on October 22, 1940, the authors noticed a slight increase in brightness to magnitude 2.80 (equality with δ Cassiopeiae) and on October 29, 1940, γ Cassiopeiae had risen to magnitude 2.65, considerably brighter than δ Cassiopeiae. It soon faded to nearly the previous low magnitude and at present, December 8, 1940, has returned to approximate equality with δ Cassiopeiae. This sudden large flare is unquestionably real and not due to accidental errors in estimation. It was noticed independently by each of the two authors and reported in *Harvard Announcement Card* No. 546.

Since the fall of 1939 the spectrum of γ Cassiopeiae has been characterized by broad diffuse absorption lines of several elements originating near the photosphere and a second set of very sharp absorption lines which arise in a shell of gas remote from the photosphere.[5] These shell lines were very strong and gave evidence of high excitation. Almost simultaneously with the increase in light, the shell lines began to fade, *i.e.,* the shell began to dissipate. At present only the strongest line, He I 3889, remains.

Other more or less obvious features in the spectrum are the emission lines of numerous elements. These lines have been fading since the fall of 1937 and at present are not conspicuous. The emission lines are produced mainly by recombination of ions and electrons; the ionization is done by strong far-ultra-violet light. Hence the atmosphere of this star at present is either far more transparent to ultra-violet radiation, or else

contains much less material than it did only three years ago.

We are greatly indebted to Dr. C. M. Huffer and Mr. Leon Campbell for permitting us the use of unpublished magnitude observations.

TABLE I

ESTIMATED VISUAL MAGNITUDES OF γ CASSIOPEIAE

J.D. 242+	Mag.	J.D. 242+	Mag.	J.D. 242+	Mag.
9165	2.35	9402	2.70	9871	2.95
9196	2.45	9426	2.70	9876	3.00
9221	2.45	9427	2.75	9878	2.90
9231	2.45	9428	2.65	9899	2.95
9245	2.60	9431	2.75	9904	2.95
9247	2.60	9433	2.70	9906	2.90
9260	2.55	9581	2.80	9910	2.95
9262	2.60	9583	2.85	9925	2.85
9275	2.60	9584	2.85	9932	2.65
9310	2.60	9605	2.85	9935	2.80
9317	2.60	9631	2.85	9940	2.95
9318	2.60	9633	2.90	9944	2.95
9319	2.60	9673	2.95	9948	2.80
9324	2.60	9703	2.95	9958	2.75
9338	2.50	9729	2.95	9959	2.80
9344	2.55	9756	2.90	9961	2.80
9346	2.55	9759	2.95	9965	2.80
9349	2.50	9784	2.90	9966	2.85
9373	2.60	9786	3.00	9967	2.80
9378	2.60	9787	2.95	9970	2.75
9392	2.60	9814	3.00	9972	2.80
9395	2.65	9815	2.95		
9400	2.65	9822	2.95		

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The Problem of Phi Persei

By OTTO STRUVE

φ Persei is one of the most remarkable objects in the sky. It is a typical representative of a small group of stars whose radial velocities vary in a regular manner, but whose velocity curves present departures from simple binary motion. Twenty-seven years ago F. C. Jordan[1] concluded that ". . . no simple orbit or combination of orbits will satisfy all these conditions . . . It seems reasonably certain that the star has extensive chromospheric and absorbing layers whose intensity of action varies regularly with phase, probably because of some tidal action, but beyond this the system is a complete riddle."

Since these words were written in 1913, several investigations of φ Persei have been published, and while they have served to collect and

systematize a large amount of observational data, they have failed to solve the puzzle of this strange object. The latest contribution is a paper by J. A. Hynek,[2] who has discussed a series of spectrograms secured at the Yerkes Observatory and supplemented with material from the new Cassegrain spectrograph of the Perkins Observatory. Hynek has discovered a number of new facts, and has attempted to give a physical interpretation of his observations. The purpose of the following remarks is to discuss this interpretation.

Stellar spectroscopy has provided many puzzles. Some of them have been solved, but others, like that of ϕ Persei, have defied all attempts. Hynek concludes that of two possible forms of the binary hypothesis "neither is without objection." Evidently, something is seriously wrong with the whole situation. Additional work along former lines gives little promise for success. Hynek has collected such a wealth of information that probably few new facts would be recognized from a study of a greater number of spectrograms.

The question is: can the problem be solved with available data, and if so, how? Before I can answer this question we must make clear just what we mean by solving the problem. When we examine the spectrum of a star, like that of ϕ Persei, we see a continuous spectrum with absorption lines and with emission lines. Our study must show whether these features come from a single source of light, or from several sources. Having settled this point we must try to secure a geometrical picture of the relative positions of the component parts of the system. The Doppler displacements of the spectral lines will, then, show how these component parts are moving. Finally, a study of the line contours and of the intensities of the lines should provide information concerning the physical nature of each constituent.

Recent advances in the study of the formation of stellar absorption lines have been so profound that there should be no particular difficulty in solving the problem within the limits outlined in the preceding paragraph. We have the data of observation, and theory provides the method of attack. There is no longer any justification for vague statements of the kind that[3] "possibly both the hypothesis of binary motion and the hypothesis of pulsation are necessary to account for the observations of ϕ Persei."

The most difficult part of solving the puzzle of ϕ Persei consists in analyzing the observations and picking out those facts which are really significant from those observations which are irrelevant or, perhaps, misleading.

The first announcement of the existence of bright lines in the spectrum of ϕ Persei was made by E. C. Pickering[4] in 1889. About ten years later Campbell and Reese[5] found that the radial velocity is variable. The radial velocities were measured and discussed by Cannon,[6] Ludendorff,[7] and Jordan,[1] and the latter recognized that the velocity curve would not be represented in terms of the usual orbital elements of a spectroscopic

binary. A useful bibliography may be found in a paper by Dustheimer.[8] Two recent papers by Schiefer[8] and Hynek[2] are, in part, devoted to the study of line intensities and line contours.

The continuous spectrum of ϕ Persei is fairly strong in the violet and the star must have a relatively high temperature. The latest determination of the spectrophotometric gradient was obtained at Greenwich.[9] It indicates a color temperature similar to that of an A5 star.

The spectral type, as determined from the general appearance of the absorption lines is B0. However, the spectrum is not normal, and it cannot be fitted within the sequence of the Henry Draper classification. Some time ago I suggested[10] for the reversing layer of ϕ Persei a type close to B3, and Hynek suggests B2 or B3. There can be no doubt that the color temperature is too low for its spectral type. The reddening may be due to great distance or to the continuous absorption of a nebulous shell,[11] as proposed by Kosirev[12] for P Cygni. It is probable that we can eliminate the effect of distance: the interstellar calcium lines are weak, although the star is in a region of the Milky Way (galactic latitude $-11°$) where distant stars normally have very strong interstellar lines. The remaining cause of reddening—that produced by the Kosirev mechanism—is in harmony with the evidence of the absorption lines.

The hydrogen lines of ϕ Persei have[2] "the usual broad, shallow, background wings, attributable to rotational and Stark broadening, on which is superposed a rather broad emission line which, in turn, is crossed by a very sharp, in general, absorption line, making the emission appear double." The sharp absorption lines have been measured by most observers. They vary in velocity between -30 km/sec and $+40$ km/sec, in a regular period of 126.626 days. Soon after maximum positive velocity, the velocity curve shows a pronounced dip to lower values which lasts for some 20 days. There may be a similar, but much smaller, "secondary variation" immediately after minimum velocity, the lines being then displaced toward higher values. The existence of this "secondary variation" is uncertain: it is not shown in Jordan's work, and Hynek is not fully convinced of its reality. But the dip soon after maximum is definitely established.

The sharp hydrogen absorption lines show no Stark effect. They must originate in a gas whose pressure is considerably lower than that of a supergiant reversing layer. But the wings suggest Stark effect of considerable strength. We conclude that there are at least two sources: a normal main-sequence B-type star, which is responsible for the Stark-effect wings, and a nebulous mass of low pressure, which produces the sharp absorption lines.

The nebulous gas is in front of the B star at all phases, but periodic variations in the intensities of the sharp lines show that the amount of matter per cm^2 is not constant.

Two years ago Wurm and I pointed out[13] that the helium line λ3965 is sharp and shows an abnormal intensity. Hynek has since shown that

the radial velocity curve of λ3965 agrees with that of the sharp hydrogen lines.

There can be no doubt that the strange behavior of the helium line λ3965 is caused by a departure from thermodynamic equilibrium, which results when the absorbing gas is located at a considerable distance from the photosphere of the exciting star. Except during a short interval each cycle, the nebulous mass shows only those helium lines, which, like λ3965, arise from metastable levels. The famous diffuse triplet lines, λλ4472, 4026, are vanishingly faint in the normal sharp-line spectrum. We conclude that the departures from equilibrium are considerable, and the dilution factor which measures the departures must be quite small. The available material justifies our making an estimate of the dilution factor. If the sharp-line spectrum were normal, λλ4026, 4472 would be much stronger than λ3965. In reality the former are at the limit of visibility. We are certainly not far from the truth when we say that the diffuse triplets are about one hundred times weaker than they should normally be. An inspection of Table 4, computed by Wurm and me[14] shows the population of levels 2^1S and 2^3P at $P = 25{,}000°$ for different values of W, the dilution factor. If the population of 2^1S is 100, then for thermodynamic equilibrium when $W = 1$, the population of 2^3P is 703. But when $W = 0.01$, the population of 2^3P is only 40. The ratio is 18. To obtain a ratio of 100 we shall have to assume approximately

$$W = 10^{-3}.$$

Strictly speaking, this procedure gives us only an upper limit for W. But Hynek states that extremely faint indications of sharp lines are visible on many plates, even outside of the peculiar range of phases which we shall discuss later. We shall, therefore, assume that our estimate of 100 in the ratios of the line intensities, and hence also of the populations (because turbulence is large and the equivalent widths are roughly proportional to the populations) is substantially correct.

If we designate by R the radius of the photosphere and by r the distance of the nebulous gases from the center of the exciting star, we have, approximately,

$$W = \tfrac{1}{4}(R^2/r^2).$$

If $W = 10^{-3}$,

$$R/r \sim 0.1.$$

The average distance of the nebulous mass from the center of the star is ten times the radius of the photosphere.

We have, as yet, no estimate of R. In fact, we have tacitly assumed that we look through the nebulous gases at a reversing layer which, among other features, shows Stark effect wings of hydrogen. Hynek, on the other hand, has suggested that these broad hydrogen lines come from another component in a binary system. It might be thought that the nebulous mass is so opaque that we are not able to see the reversing layer, even if it existed. This is the case in P Cygni and in several other

stars. But in ϕ Persei the intensities of the sharp absorption lines are much smaller than in P Cygni. I should, therefore, expect that the opacity of the nebula is not sufficient to completely block the light of the lower layers, and I consider it much more probable that we actually see the reversing layer of a normal B star through the nebula. There is another important argument in favor of this view. The central intensities of the sharp hydrogen and helium λ3965 lines are quite small. Without correcting for instrumental effects, Hynek finds for Hϵ some 40 per cent and for Hδ some 50 per cent intensity at the center. Since the lines are narrow, it is probable that the real values are even smaller. It is difficult to see how such strong lines could originate, if the relatively high central intensities of normal broad hydrogen lines from a rapidly-rotating, Stark-broadened, B star were superposed over the sharp absorptions. This is especially true in the case of helium λ3965, which, according to Hynek, is not present in the broad-lined star. Accordingly, the continuous spectrum of the broad-lined star should, on Hynek's hypothesis, overlie the sharp helium line of his "hydrogen star." It is fairly certain that the spectrogram shown in Plate III of my paper with Wurm disproves this conclusion. Hence, I think it is safe to suppose that the broad-lined reversing layer is actually seen through the nebula.

Now, this broad-lined star is peculiar only in one respect: its absorption lines of helium, hydrogen, and magnesium λ4481 indicate very rapid axial rotation—of the order of 300 km/sec. Otherwise, the relative intensities of the lines are normal for spectral type B3. Here we encounter some contradictory evidence. Hynek suggests[15] that a "hump about six angstroms to the red in many of the profiles, especially during the first quarter of the cycle, is apparently real and is probably due to the O II, N II blend at λ4478." If this identification were correct, it would place ϕ Persei among the most abnormal stars on record. As a matter of fact, the two lines near λ4478 are very faint, and usually are present only in stars in which many other lines of O II and N II are very strong and sharp. Since all strong laboratory lines of O II and N II are either absent or extremely weak in ϕ Persei, I believe the identification is not correct, and the hump on Hynek's curves must be the Mg II line λ4481 of the broad-lined star. This point is important, and I think it shows how a single wrong observation may prevent us from finding the solution of our problem.

If our hypothesis of the semi-transparent shell of nebulous matter is correct, then we can assume for R a value consistent with other main-sequence B-type stars. We shall suppse $R = 10R_{\odot} \approx 10^{7}$km. Certainly, the star is not a supergiant, and our estimate must be fairly close to the truth. Our previous results give for the nebulous shell $r = 10^{8}$ km.

We have succeeded thus far in distinguishing between two spectroscopic sources: the normal B star having a rapid axial rotation and the peculiar nebulous shell whose average radius is about ten times larger

than that of the star. Are there any other sources? In the past, astronomers have sometimes tried to distinguish between emitting and absorbing layers of a gas.[16] In hydrogen the distinction is artificial: there is no reason why recombinations should occur mostly in one layer, while line absorption should be concentrated in another. McLaughlin[16] had thought that the ionizing radiation would be rapidly exhausted so that "the outer atmosphere would thus be denied the large supply of energy required for the production of strong emission lines, and the chief observed effect of the atoms of the outer layers is found in the absorption lines which bisect the emission."

I am not sure that this view is correct. Surely, line absorption in the Lyman series will also rapidly deplete the supply of energy required to produce large populations in the second energy level of hydrogen. There is little or no reason to suppose that the emission lines originate in a source other than that which gives rise to the sharp absorption lines. But this does not mean that the effective radius of the shell is the same for absorption and emission lines, if the shell has an appreciable thickness.

About twenty days after maximum positive velocity the spectrum develops strong, sharp cores in the helium lines λλ4472, 4026. These cores are visible for about 20 days and then disappear. Hynek believes that faint vestiges of the sharp cores remain visible at other phases, but the important thing is that they are strong only between phases 20 days and 40 days after maximum velocity. Hynek has devoted much attention to these sharp lines and has attributed them to the spectrum of the secondary component of a binary system, the primary component of which he has identified with the sharp-line spectrum of hydrogen and helium λ3965. In support of this contention he presents velocity curves for λ4026 and λ4472 which are "opposite in phase and of twice the amplitude of the singlet line (λ3965)."

Convincing as these curves may appear, Hynek's conclusion is extremely doubtful. When we compare the illustrations in my paper with Wurm,[13] we cannot doubt that the sharp lines of λλ4026, 4472, which are present between phases 20 and 40 days after maximum velocity, are so completely different from the hazy diffuse lines at other phases that they belong to altogether different sources, and that a curve based upon a mixture of measurements of sharp and diffuse lines is largely fortuitous. It should be remembered that ϕ Persei is not an eclipsing variable. Hence, the lines of a secondary component, if present at all, should change little in appearance and equivalent width. No normal star is known to behave like Hynek's hypothetical secondary component, which he describes as "a fainter star of essentially the same spectral class and separated from the primary by more than an astronomical unit . . ., which probably does not have an extensive atmosphere since no dilution effects are observed . . ."

Let us consider the nature of this hypothetical secondary spectrum. The triplet lines of helium undergo tremendous variations in contour

and intensity. But the diffuse singlet lines, of which λ4009 is a member, remain broad and hazy at the same time when λλ4026, 4472 develop strong, sharp cores. This is not normal, and strongly suggests that dilution is present in the source which gives rise to the sharp lines of λλ4026, 4472. Even more convincing is the absence of a sharp line at Mg II 4481, when He I 4472 is sharp. If Hynek's secondary spectrum were that of a star, the magnesium line should follow the variations of the He I 4472 line. The absence of the magnesium line is a reliable indication either of a very early spectral type or of appreciable dilution of radiation. The early spectral type is ruled out by the absence of other lines, such as Si III, Si IV, etc. We must conclude that the source of the sharp helium lines at phases 20 to 40 days after maximum velocity is not a star but a mass of gas sufficiently far removed from the exciting photosphere to give clear indication of dilution effects.

I know that this conclusion appears to contradict some of Hynek's observations. I can only plead that the latter must be irrelevant. For example, when Hynek finds that λ4026 shows faint sharp components when the velocities from the hydrogen lines are positive, while λ4472 shows such components when the velocities of the hydrogen lines are negative, I can only say that atomic theory precludes an interpretation of these observations in terms of numbers of atoms producing the two successive members of the helium series ($2^3P - n^3D$). Hence, the observations must be irrelevant and must find an explanation in some unrelated phenomenon, such as blends. Until the different behavior of these two lines has been elucidated, a velocity curve based upon the faint cores of these lines has no physical content.

If the strong, sharp helium lines λλ4026, 4472 at phases 20 to 40 days are not caused by a secondary component they must come from a mass of gas projected upon the rapidly rotating B star during these 20 days. Hynek's measures during this interval refer to the sharp lines only. They show a marked change in velocity, from —40 km/sec at phase 20 days to +20 km/sec at phase 40 days after maximum velocity. The trend of this variation in velocity is opposite to that shown by the sharp hydrogen lines and by He I 3965. Since we cannot adopt Hynek's interpretation, we must seek for some other mechanism.

I believe the clue to our puzzle lies in the fact that the critical interval from phase 20 to phase 40 agrees very nearly with the time of the dip in the velocity curve shortly after maximum velocity. From the sharp helium lines λλ 4026, 4472 and the absence of Mg II 4481 and He I 4388, 4009, etc., we concluded that the source shows appreciable dilution. But the very fact that the ($2^3P - n^3D$) lines λλ 4472, 4026 are visible at all, while ($2^1S - n^1P$) λ 3965 is not appreciably strengthened, shows beyond any doubt that the dilution is less than in the shell, and that the gas must lie inside the shell.

It is practically certain that hydrogen must also be present in this new mass of gas. The question is: will these hydrogen lines be sharp or

broad? Here again we are confronted by contradictory observational evidence. On the one side we have unmistakable indications of dilution, and hence of very low density. On the other, we have Hynek's suggestion that the forbidden He I line λ 4470 may be present. If the Stark effect is strong enough to produce λ 4470, then the hydrogen lines must be broad. I believe Hynek inclines toward the idea that the broad hydrogen wings and the helium cores of λλ 4472, 4026 actually do belong to same source—namely to his secondary component. But the absence of Mg II 4481 and of sharp cores to λλ 4009, 4144, 4388 is, in my opinion, more convincing than the somewhat problematical presence of forbidden He I 4470. I, therefore, venture to suggest that the pressure of the gas producing sharp λλ 4026, 4472 is low and that there is no appreciable Stark effect. In that case the new mass of gas must produce sharp lines of hydrogen which will blend with the sharp lines produced in the shell and will fully account for the dip in the velocity curve.

The conclusion is strengthened by the fact that He I λ 3965, which follows, in general, the velocity curve of the hydrogen lines, also shows the dip, but its depth is less than that of the hydrogen lines. Of course, λ 3965 must also occur in the spectrum of the new mass of gas at phases 20 to 40 days. But if the dilution of radiation is not as pronounced as it is in the shell the blending effect will be relatively small, and the dip will be shallow.

On Hynek's hypothesis this interpretation is ruled out because the sharp hydrogen lines are not strong during the dip of the velocity curve, but are broad and present a "washed out" appearance. I do not believe that this objection is serious. We must think of a stream of gas emanating from the B star at a point which happens to be in the line of sight between phases 20 to 40 days. This stream of gas flows out from a rapidly rotating star and is deflected from a straight path by rotation, as modified by conservation of momentum. We are looking through the curved stream and see, within the line of sight, velocities of different radial components. The effect will be a line showing appreciable turbulence broadening. The absorption spectrum of the outer shell, which is doubtless produced by the stream that we are discussing, need not give rise to strong lines at these particular phases.

We turn to the interpretation of the velocity curve of the hydrogen lines and of He I 3965. If the dip is merely the result of blending, the remaining curve may well be due to orbital motion. The velocity curve by Jordan is perhaps better suited to illustrate this point than the one by Hynek. At phase 20 days Hynek finds for the sharp lines of the outflowing stream —40 km/sec. The blended velocity is about —5 km/sec, and the true velocity of the shell is perhaps +10 km/sec. At phase 40 days, the stream gives +20 km/sec; the blended velocity is about 0 km/sec, and the true velocity of the shell is perhaps —10 km/sec. The ratios of the "weights" of the blended components are not exactly the same, but this is not to be expected.

If the corrected velocity curve of the shell is interpreted as binary motion of one component, the suggestion immediately arises that what we have interpreted as the stream of gas flowing from the B star is in reality an eclipse of the B star by the atmosphere of the second, invisible component of the double star. This type of phenomenon is now well known from the work on ζ Aurigae, ϵ Aurigae, VV Cephei, and μ Sagittarii. At my request, Dr. F. E. Roach[17] at Tucson and Dr. C. T. Elvey[18] at the McDonald Observatory have observed ϕ Persei with photoelectric photometers during the critical phases. No eclipse was found. It is still possible that an atmospheric eclipse takes place without giving rise to a measurable amount of general absorption. But I believe that the nature of the spectrum is against this interpretation. If the companion is a normal B star and is able to excite its own atmosphere, then there should be no dilution. On the other hand, if the companion is of late spectral type and the helium lines are excited by the primary component, then the dilution of the radiation should be even stronger than in the hydrogen shell. The fact that we observe intermediate dilution speaks in favor of the stream hypothesis.

This does not necessarily mean that the binary hypothesis must be abandoned. But we must be careful in remembering that the velocity curve refers to the radial motion of the shell, not to that of the massive star inside. Hynek had considerable difficulty in measuring those helium lines which are broad at all phases. We do not know whether they follow the curve of the sharp hydrogen lines, but we do know from the measures of Hynek and of Schiefer that the emission lines of hydrogen show almost no variation in velocity. If they come from the same shell as the sharp absorption lines, and if the entire shell shares the orbital motion of the primary component, then this result would remain without explanation.

But the radius of the shell is $r = 10^8$ km. If the displacements of the hydrogen lines are interpreted as binary motion, Hynek finds for the primary component $a_1 \sin i = 6.9 \times 10^7$ km. The two quantities are of the same order of magnitude.

The constancy of the period, the regularity of the hydrogen velocity curve and the existence of a definite point of out-flow on the surface of the primary support the idea that ϕ Persei is a binary system whose period is 126 days. But the amplitude and the shape of the hydrogen velocity curve probably do not apply to the motion of the primary component. It is not probable that the amplitude of the displacements of the broad absorption lines, 2K, exceeds that of the sharp hydrogen lines. If it did, Hynek would probably have found it. It may be considerably smaller. But by a well-known formula[19]

$$a \sin i = \text{const.}\ K \times P \sqrt{1 - e^2}.$$

Hence, the true value of a sin i for the primary component may be less than 7×10^7 km. The nebulous shell extends at least as far as the cen-

ter of gravity of the system, and may reach beyond it. It is clear that we cannot assume that its motions will be identical with those of the massive primary component. The dynamical problem of a large nebula in the gravitational field of a binary system is similar to that attacked by Kuiper[20] in the case of β Lyrae. It is entirely possible that those portions of the nebulous shell which are in front of the primary component will show a velocity curve of appreciable range, while the integrated emission from the entire shell, giving rise to the bright lines will show little variation. This is a dynamical problem which has not yet been solved.

In discussing the velocity curve of the sharp hydrogen lines, I have tacitly assumed that the changes in Doppler displacement with phase correspond to changes in the angle under which we observe the system. In other words, we assumed that the displacements do not vary in time, but that they give a different value depending upon the longitude under which we observe the primary component.

This assumption must be justified. Indeed, a number of investigations have assumed that the displacements vary in time. For example, Curtiss[21] proposed the hypothesis of radial pulsations and Dustheimer[3] tried to combine it with the hypothesis of binary motion. Pure pulsation is probably not possible. If we regard a sin i as the semiamplitude of the pulsation,[22] we see at once that a change in radius of the order of 10^8 km for a star whose normal radius is 10^7 km is not possible without large fluctuations in light. Such fluctuations are not present. A pulsation of the shell alone is also improbable: we should observe changes in the intensities of the absorption lines resulting from the changes in the density of the pulsating shell. Those changes in the absorption lines which have been observed are not consistent with the hypothesis.

The rapid rotation of the primary component of ϕ Persei, and the disturbing action of the invisible secondary component must account for the outflow of gas at the equator of the primary in the direction of the secondary.

There remains the problem of the bright lines. Their great widths, of the order of 7A, must be due to Doppler effect. There is no evidence of rapid expansion in the absorption lines. Hence it is reasonable to attribute this width to rotation and revolution in the gravitational field of the binary. We have seen that the centers of the emission lines, defined as the means of measurements of violet and red edges, show little change in velocity. This is, at least qualitatively, in agreement with the fact that the shell extends as far as the center of gravity of the system, and perhaps beyond it. But we also know that there is a periodic variation of V/R (using McLaughlin's designation), and this may well be interpreted as a Doppler effect of the integrated line produced by the individual atoms. It would be interesting to pursue this idea further. V/R is large when the sharp hydrogen absorption line has a red-shift, and V/R is small when this line has a violet-shift. There is no trouble about

explaining the opposite trend shown by the emission and sharp absorption lines. But it is futile to speculate on this point until we know whether the broad B3-lines show orbital motion.

There is one other bright star, namely ζ Tauri, which shares many of the characteristics of ϕ Persei. A study of the spectroscopic features of ζ Tauri will be useful in testing the proposed interpretation.

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An Experiment in Interstellar Reddening

By JESSE L. GREENSTEIN

INTRODUCTION

The actual nature of the substances contributing to the phenomena of interstellar absorption is still unknown. It is easy to show from simple physical principles that the particles which are of most importance must be small compared to the wave-length of light. This is true of both the general interstellar haze and the great dark nebulae. At present there are few laboratory experiments in common use which demonstrate the nature of the absorption and reddening produced by small particles. We therefore wish to present, in this coöperative paper, an outline of simple experimental techniques for producing small particles. The materials required are easily obtainable, and many of the properties of the particles may be discussed without elaborate measurements. Two important types of information are of significance in studying the nature of the interstellar particles. We may investigate the dependence on wave-length of the absorption between us and the star. The stars are observed to be

reddened, and the law of reddening has been established. We may also estimate the mass of material between us and the star, and derive the "mass absorption coefficient," that is, the amount of absorption of light produced by a given mass of matter in space.

It is known from observations of space reddening that the absorption, $\kappa(\lambda)$, increases towards the violet in an amount roughly proportional to the frequency of light concerned, *i.e.*,

$$\kappa(\lambda) = \kappa_0/\lambda.$$

In the earth's atmosphere, we know that the scattering by the gases follows Rayleigh's law,

$$\kappa(\lambda) = \kappa_0/\lambda^4.$$

This is true for all ordinary gases. Violet light is less strongly absorbed in space than in our atmosphere, and we can definitely state that gases do not contribute appreciably to space reddening. Studies based on the classical electromagnetic theory of light have shown that small, solid particles are capable of scattering and absorbing light differently from gases. For small particles of certain sizes and composition the absorption may depend on wave-length in a manner similar to that in space.

The most significant clue to the nature of the absorbing material in space is the mass absorption coefficient. It is known that the absorption for photographic light is roughly one magnitude per thousand parsecs in the Milky Way. The simple equation governing the absorption of light is

$$I(\lambda) = I_0(\lambda)e^{-\kappa(\lambda)r}, \tag{1}$$

where $I_0(\lambda)$ is the original intensity, $I(\lambda)$ the intensity of the light reaching the observer, and r the distance. If we convert to stellar magnitudes, we see that the dimming of light $\Delta m(\lambda)$ is

$$\Delta m(\lambda) = 1.086\,\kappa(\lambda)r. \tag{2}$$

Then $\kappa(\lambda)$ is close to 3×10^{-22} cm^{-1}. We have indirect means for estimating the mass of dark matter in space, and it has been found that there is less than 3×10^{-24} gm cm^{-3} of such material. The absorption per gram of material is larger than 100 cm^2 gm^{-1}. This means that only 0.01 grams of material in a column one square centimeter in cross section between us and the star dims the light of the star by one magnitude!

Normal terrestrial gases have much smaller absorption coefficients. For example, the earth's atmosphere contains roughly 1000 grams above each square centimeter. Yet we know that the dimming of photographic light by the atmosphere is only about 0.4 magnitudes. The mass absorption coefficient is only 4×10^{-4} cm^2 gm^{-1}. It is obvious that gases in space are incapable of appreciably dimming star light. For example, if gases were to produce an absorption of one magnitude per thousand parsecs, the gas in one cubic parsec would weigh twelve thousand times as much as the sun. We know that the dark matter in a cubic parsec weighs

less than one tenth as much as the sun.

Again let us consider phenomena of the earth's atmosphere. We have all seen how easily opaque clouds form in a clear sky. No more water is present in a cloud than in a clear patch of sky—but in the cloud the water vapor has condensed to form water droplets. These small drops have been investigated by meteorologists, who find that they range in size from 2×10^{-4} cm to 10^{-3} cm, or larger. If we remember that the wave-length of light is about 5×10^{-5} cm, we see that while the water droplets are small, they are larger than a wave-length. Since clouds do not appreciably redden the sunlight, we see that the absorption coefficient is independent of wave-length for particles larger than a wave-length of light.

We must study the properties of solid particles smaller than a wave-length of light since we see that they will be efficient absorbers, and will produce reddening. While the materials we will use are not reasonable candidates for occurrence in interstellar space, their essential properties in small particle form are significant. A group of graduate students at the Yerkes Observatory have carried through a set of experiments with colloidal particles, the results of which are described below. The equipment available was perhaps more elaborate than would be normally available for a laboratory class, but the methods of observation can be simplified as required, and most of the phenomena are seen by simple inspection.

Absorption and Scattering by Colloidal Rosin

Louis Henrich, Wasley Krogdahl, and Ralph Williamson

Small particles of rosin can be produced in a hydrosol, or colloidal suspension, by simple means. A saturated stock solution of commercial rosin in denatured alcohol was prepared—0.5 gm of rosin per 100 cc of alcohol. Rosin is insoluble in water, and therefore when this stock solution is mixed with water the colloidal particles of rosin are formed. The alcohol solution should be added to the water slowly and with vigorous stirring. A rate of one-half cc per second is convenient; pipettes are useful, and if available, they permit accurate measurement of the mass of material added. Convenient mixtures can be obtained with 0.08 to 0.20 grams of rosin per liter of water. An inexpensive rectangular aquarium, ten inches in length, was used for these experiments. The entire tank became a highly turbid bluish-white with this amount of rosin. The light transmitted was strongly reddened and dimmed.

The actual experimental arrangement used consisted of a projection lantern, the aquarium with the solution, and a calibrating step-slit spectrophotometer. The lantern was focussed to obtain a parallel beam, and black paper masks were used to limit the beam through the tank, and reduce stray light. The spectra photographed with the spectrophotometer permitted the measurement of the intensity of light passing through the solution, as a function of wave-length. A visual spectroscope could

also be used, if available, to demonstrate the weakening of blue light by the solution; an ordinary exposure meter with yellow and blue filters will also yield measures of the absorption. The spectrograms were taken through the tank filled with pure water, and through rosin suspensions of various densities. The plates were measured in a microphotometer. The differences between the apparent magnitudes of the transmitted light through the water, and through various suspensions were then obtained as a function of wave-length.

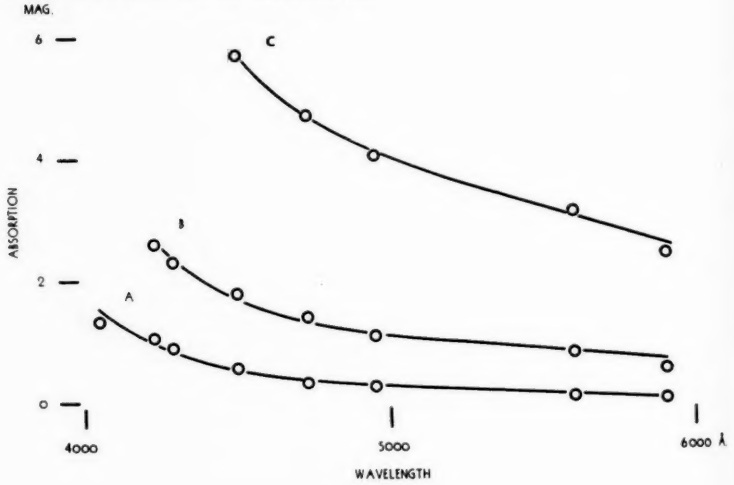

FIGURE 1

ABSORPTION OF LIGHT (IN MAGNITUDES) AS A FUNCTION OF WAVE-LENGTH FOR A BEAM OF LIGHT TRAVERSING 25 cm OF SOLUTION.

Curves A, B, and C represent the following concentrations of solution, respectively:

Solution A contains 0.8×10^{-4} grams of rosin per cc.
Solution B contains 1.4×10^{-4} grams of rosin per cc.
Solution C contains 2.0×10^{-4} grams of rosin per cc.

The results for three different suspensions of colloidal rosin are given in Fig. 1. The absorption through the tank depends on the amount of material; the actual mass absorption coefficient seems to increase with increasing density of colloidal rosin, apparently because of a change of average particle size. Since we know how much rosin has been added we can determine the amount of material in one square centimeter cross section through the tank. For example, in solution B, there were 3.6×10^{-3} gm cm^{-2} of rosin for an absorption of 1.1 magnitudes at λ5000. The absorption would be 310 magnitudes per gram of material in a square centimeter column! Only three milligrams per square centimeter are required to dim light by one magnitude. The increase of the absorption towards the violet is seen, in Fig. 1, to be more rapid than

$1/\lambda^4$, and, of course, more rapid than the interstellar absorption coefficient. The rosin particles are apparently smaller than a wave length of light, and redden light relatively more than the interstellar material.

The scattered light, seen when the beam of light through the tank is viewed sideways, is definitely bluer than the original light source. Reflection nebulae, such as that surrounding the Pleiades, show the continuous spectra of the stars that illuminate them. The scattered light in our experiment exhibits some interesting phenomena displayed by reflection nebulae. The beam, initially blue, becomes strongly dimmed and reddened at the far end of the tank. While the particles scatter more blue light than red, yet they also redden the light that reaches the far end of the tank, and prevent the "nebula" from being very blue. (For that reason, real nebulae are never as much bluer than the illuminating star as our terrestrial sky is bluer than the sun.) If the beam is viewed through a piece of Polaroid, strong polarization is found, particularly for light scattered at right angles to the incident beam. Polarization has been observed in reflection nebulae. The light scattered forward is much stronger than the light scattered backward, as can be seen by comparing the brightness of the beam seen from directions making angles of 30° and 150° with the incident light. Such behavior is expected for particles smaller than a wave-length of light.

An Experiment with Metallic Silver Particles

Miss Frances Sherman, Edwin Bailey, and John O'Keefe

The optical properties of metals differ greatly from those of dielectric substances. The energy of the electromagnetic radiation is essentially only changed in direction, *i.e., scattered,* in the previous experiment, and in dielectrics and gases in general. In metals, however, the radiation is *absorbed* and converted into thermal energy of the electrons in the metal. For small metallic particles, while the scattering does occur, it is small compared to the absorption process. The result is a higher total mass absorption coefficient, and relatively little scattered light.

A colloidal suspension of silver particles can be prepared by the reduction of silver nitrate by tannic acid. The formula is:

Silver nitrate, 1% solution	5 cc
Dilute ammonia, 0.3% solution	about 2 cc
Tannic acid, 0.5% solution	100 cc

First take the 1% silver nitrate solution and add the ammonia slowly. The ammonia must be very dilute; it is added by drops until the cloudy precipitate which forms in the silver nitrate just disappears. Then the tannic acid solution is added to form the colloidal silver particles. The result is a very concentrated, deep red, colloidal suspension of silver, with about 2×10^{-4} gm cm^{-3} of silver. Roughly three parts of this in 1000 parts of distilled water gives a yellow solution of moderate opacity in the 25 centimeter tank. The final solution strongly reddens the trans-

mitted light, but the scattered light is very weak, and bluish green. The suspension is stable if distilled water is used throughout.

The transmission through the final solution was obtained as described in the previous experiment, with the result shown in Fig. 2. The increase of the absorption to the blue is quite steep, much faster than $1/\lambda^4$

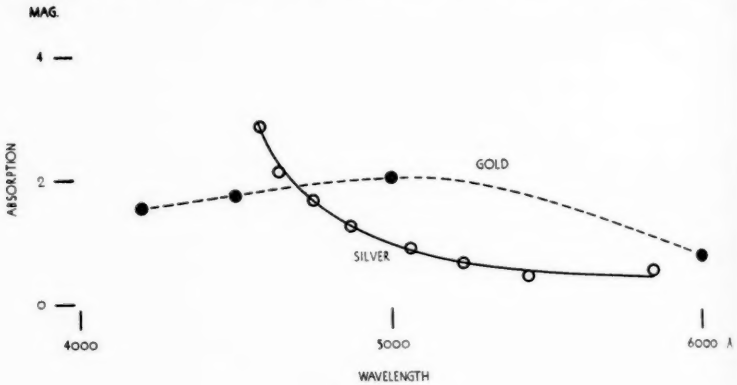

FIGURE 2

ABSORPTION OF LIGHT IN METALLIC COLLOID SUSPENSIONS.

The full curve for 25 cm of silver suspension corresponds to 5×10^{-7} gm per cc. The dotted curve is for gold colloid.

in this spectral region. The actual nature of the curve corresponds to that expected for silver on the Mie theory of absorption of light by small metallic particles. The large mass absorption coefficient derived, about 7×10^4 cm^2 gm^{-1}, is of particular interest in this experiment. Only 0.014 milligram of material in a square centimeter column would produce one magnitude absorption!

The mass absorption coefficient, $\kappa(\lambda)$, is in general very high for metallic particles. If the particles are smaller than a wave-length of light, it can be shown that:

$$\kappa(\lambda) = (6\pi/\lambda s)\, F(\lambda), \tag{3}$$

where s is the specific gravity of the material, and $F(\lambda)$ a function of the optical properties of the metal. $F(\lambda)$ is usually of the order of 0.1 to 0.8. For small silver particles $\kappa(\lambda)$ should be of the order of 10^4. The higher value observed in our experiment is probably due to the phenomenon of "optical resonance."

The scattered light from the metallic colloid is found to be very weak. The beam of scattered light is blue, but is scarcely visible in its passage through the tank. The polarization of the scattered light can be seen with Polaroid. The weakness of the scattered light arises, on the basis of the Mie theory, from the predominance of true absorption over

the scattering process in a metal.

It is possible to prove that the color phenomena in this colloidal suspension arise only from the small size of the particles. By concentrating some of the original suspension by osmosis through a membrane, such as sausage casing, the colloidal particles grow large enough to be seen. Then the color phenomena disappear, and no coloring will be found in the water outside the membrane.

An Experiment with Gold Colloid

Fergus Wood

If a metal is burned in an underwater arc, colloidal particles are produced. An arc may be maintained between two gold electrodes in water rendered slightly conductive. Ten amperes at 110 volts are satisfactory. It is difficult to establish what fraction of the burnt metal goes to form a heavy precipitate, and what part forms small particles. The mass of the colloidal gold is therefore not accurately known. On filtering, a clear salmon-colored solution is obtained; the small particles remain in suspension.

A diluted suspension of one part of colloid to three of water gave measureable transmissions. The absorption, in magnitudes, was obtained as in the above experiments; the results are given in Fig. 2, as a function of wave-length. Perhaps the most interesting feature of the absorption curve is the existence of a maximum absorption in the yellow-green region of the spectrum. This is confirmed by the appearance of the solution by transmitted light. Such a maximum will arise from a corresponding maximum in the function, $F(\lambda)$, in equation (3). The optical properties of gold do in fact predict such behavior, for particles of radius less than 3×10^{-6} cm. We are able, in other words, to determine the size of the sub-microscopic gold particles by their absorption of light. Similarly, the astronomer hopes to determine the nature of interstellar matter by its observed transmission and scattering powers.

Yerkes Observatory, August, 1940.

Planet Notes for April, 1941

By R. S. ZUG

Note: Greenwich Civil Time is employed unless otherwise stated. To obtain Eastern Standard Time subtract 5 hours, Central Standard Time, 6 hours, etc. The planetary phenomena are described as they are to be seen from latitude 45° N. The data are taken chiefly from the *American Ephemeris and Nautical Almanac*.

Sun. Apparent positions of the sun for April 1 and April 30, respectively, are $\alpha = 0^h\,40^m.0$, $\delta = +4°\,18'.3$; $\alpha = 2^h\,27^m.4$, $\delta = +14°\,34'.9$. The sun will be moving through the contellations Pisces and Aries during April.

		h	m
First Quarter	Apr. 5	0	12
Full Moon	11	21	15
Last Quarter	18	13	3
New Moon	26	13	23

Mercury. The planet Mercury will be situated in the morning sky during April, but will be quite inconspicuous. Greatest western elongation occurred March 25.

Venus. Venus reaches superior conjunction April 19, 7^h, at which time the planet will be situated 1° 1′ to the south of the center of the sun's disk. At conjunction, the planet will be 160,577,000 miles from the earth, and will appear as a disk 9″.7 in diameter. The stellar magnitude will be —3.5 at the time.

Mars. Mars will be a morning star of stellar magnitude +0.9, during April, situated in the constellation Capricornus. Data concerning the distance and telescopic appearance of Mars are tabulated on page 31, of the January, 1941, issue of POPULAR ASTRONOMY.

Jupiter. Jupiter will be an early evening star during April.

Saturn. Saturn is also situated in the evening sky. By the end of April, however, the planet will set only an hour after the sun.

Uranus. Uranus is unfavorably situated in the early evening sky. The planet will reach conjunction in May.

Neptune. Neptune is now favorably placed for evening observation. The planet is situated in the constellation Virgo. A chart illustrating its apparent motion through telescopic stars is to be found on page 35 of POPULAR ASTRONOMY for January, 1941.

Asteroid Notes

By HUGH S. RICE

There are now no less than 1513 asteroids whose elements and ephemerides are computed by the Coppernicus-Institut at Dahlem, Germany. The last 54 have, in most cases, not received their permanent names, but are still known by their provisional names.

Observers at this time may have the unusual opportunity of observing *all* of the Big Four asteroids with small telescopes.

CERES, the number 1 minor planet, gradually approaching its time of opposition to the sun—which takes place in June—, is now getting to be quite well placed for observation, with stellar magnitude ranging from 8.5 to 7.9 in the interval from March 1 to May 1. The asteroid is in the Milky Way in Sagittarius during this period, being 4° west of μ Sagittarii on the evening of March 2, from which point it travels eastward to a point 3½° north of λ Sagittarii by March 29; and at the end of April it can be found 4° northeast of λ, which position is near its stationary point. There are many Messier objects near the planet's apparent path. Ceres is in conjunction (in R. A.) with the last-quarter moon on March 20 at approximately 5 A.M., E.S.T., and Ceres is about 3¾° south of the moon in geocentric position. Another conjunction of Ceres and the moon occurs on April 16, at about 8:00 P.M., E.S.T., when Ceres is roughly 4½° south of the moon.

PALLAS is likewise coming into favorable observing conditions. It is 2° west of χ Ophiuchi on March 2, 3° northwest of α Herculis on April 3, and 5° southwest of δ Herculis on April 30. The magnitude of Pallas ranges from 8.8 on March 1 to 8.6 on May 1.

JUNO also is nicely placed for all telescopes at this time. It is 3½° southwest of π Leonis on March 2, 1° northwest of ο Leonis on April 3, and 1° northeast of R Leonis on May 1. It appears to be heading almost straight for Regulus, in its apparent course. The magnitude goes from 8.6 on March 2 to 9.5 on May 1. A conjunction of Juno with the moon takes place on March 11, about 7:00 A.M., E.S.T., with the asteroid 3° south of the moon. Another conjunction occurs on April 7, at 3:00 P.M., E.S.T., which, on account of daylight, makes the aspect invisible in the United States; however, in this case it is so close that it is likely an occultation in some regions.

VESTA is not far away from Juno in the sky. On March 2, it is 1° east of λ Leonis; on April 3, 2½° south of κ, and on May 1, 1½° southeast of λ. The magnitude ranges from 6.7 to 7.2 during the two months, which indicates it is still very bright for an asteroid. Vesta also undergoes conjuncton with the moon: the first is on March 11 at 1:00 A.M., E.S.T., and the other on April 7 at 8:00 A.M., E.S.T.; but in each case the conjunction is not close, the asteroid being 12° north of the moon at both occurrences.

Besides the coincidence that all four of the largest minor planets are visible for this two-month period, it also happens that there are almost *no others visible;* that is, there are none brighter than magnitude 10.3, that come to opposition with the sun after March 1 and before April 30, with one exception—27 Euterpe, of magnitude 9.7—in Virgo.

Hayden Planetarium, American Museum of Natural History,
New York City, February 18, 1941.

Occultation Predictions

(Taken from the *American Ephemeris*)

Date 1941	Star	Mag.	IMMERSION Greenwich C.T.	IMMERSION *a*	IMMERSION *b*	IMMERSION Angle E from N	EMERSION Greenwich C.T.	EMERSION *a*	EMERSION *b*	EMERSION Angle E from N
OCCULTATIONS VISIBLE IN LONGITUDE +72° 30′, LATITUDE +42° 30′			h m	m	m	°	h m	m	m	°
Apr. 1	75 Tau	5.3	23 7.2	—1.3	—2.7	125	0 9.4	—1.4	+0.5	227
2	275 B.Tau	6.5	2 22.0	..	..	157	2 45.0	..	..	201
2	α Tau	1.1	3 10.0	+0.2	—1.4	100	.. ..			
3	111 Tau	5.1	2 17.8	—0.2	—2.0	116	3 15.7	—0.2	—0.9	250
4	287 B.Ori	6.2	3 55.8	+0.3	—2.4	136	4 41.2	—0.1	—0.5	239
8	89 B.Leo	6.3	6 5.5	—0.3	—2.0	133	7 0.0	—0.3	—1.3	267
8	π Leo	4.9	7 14.2	+0.1	—2.4	153	7 53.1	0.0	—0.7	244
10	9 B.Vir	6.2	5 29.0	—1.0	—2.0	141	6 30.3	—1.3	—1.1	267
14	θ Lib	4.3	8 10.1	—1.7	—0.9	114	9 22.8	—1.5	—0.8	267
16	305 B.Oph	6.4	8 7.4			19	8 31.2			345
17	BD-18° 5155	6.3	10 29.6	—2.2	—1.0	119	11 33.5	—1.3	+0.6	223

OCCULTATIONS VISIBLE IN LONGITUDE +91° 0′, LATITUDE +40° 0′											
2		α Tau	1.1	3 16.9	0.0	−2.2	123	4 8.2	−0.2	−0.3	236
3	111	Tau	5.1	2 17.9	−0.4	−3.6	144	3 3.7	−1.4	+0.8	222
4	124	H⁴Ori	5.7	0 59.0	−2.3	+1.2	54	2 1.6	−1.0	−3.3	318
6	30	B.Cnc	6.1	6 39.5	−0.2	−1.3	98	7 35.6	+0.2	−1.6	291
8	83	B.Leo	5.9	4 42.1	−2.3	+0.4	63	5 29.7	−0.3	−3.3	344
8	89	B.Leo	6.3	6 4.3	−0.3	−3.0	159	6 50.0	−1.3	−0.5	246
8		π Leo	4.9	7 26.3	..	..	183	7 44.3	..	..	218
10	9	B.Vir	6.2	5 20.4	..	..	178	5 56.6	..	..	235
14		θ Lib	4.3	7 41.5	−1.5	−0.8	132	8 51.0	−2.1	+0.2	258
16	305	B.Oph	6.4	7 18.6	−1.8	+2.4	52	8 12.7	−1.1	−0.6	319
17	BD-18° 5155		6.3	9 53.2	−1.9	−0.3	122	11 0.5	−2.0	+1.3	229
OCCULTATIONS VISIBLE IN LONGITUDE +120° 0′, LATITUDE +36° 0′											
4	292	B.Ori	6.5	4 38.8	−1.5	−0.6	77	5 47.0	−0.5	−2.3	301
5		λ Gem	3.6	6 49.9	−0.5	−1.6	109	7 52.4	−0.2	−1.4	277
6	30	B.Cnc	6.1	6 34.6	−0.6	−2.4	137	7 34.2	−0.9	−0.9	258
7	209	B.Cnc	6.5	8 55.1	−0.2	−1.8	123	9 51.6	−0.1	−1.2	274
8	83	B.Leo	5.9	3 39.4	−1.9	−0.6	115	5 2.4	−2.0	−0.9	291
9		*d* Leo	5.0	9 16.8	−0.5	−2.6	152	10 6.6	−0.9	−0.8	254
13	22	B.Lib	6.4	4 40.5	−0.9	+2.5	62	5 19.8	0.0	−1.4	339
15	90	B.Oph	6.5	8 58.7	−2.0	+1.9	63	9 59.5	−1.3	−1.0	319
16	305	B.Oph	6.4	6 47.3	−0.2	+1.0	96	7 47.3	−0.5	+0.8	279
17	BD-18° 5155		6.3	9 29.7	..	..	166	9 48.2	..	..	196

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

The number of meteors reported in any given year by the American Meteor Society and its numerous collaborators varies greatly due to circumstances. One of the chief of these is the presence of bright moonlight on the dates when the main annual meteor showers appear. The second is the amount of publicity given the subject by the press. It so happens that 1940 was unfortunate in both these regards.

However, the following table will show that interest was widespread and reports numerous. Actually, it is not possible to make such a table represent quite all that was done. Arbitrarily, we do not count it a "night's work" for less than a full hour of observing. However, all meteors seen are put in unless observations, on odd pieces of paper or entered in the wrong places on standard record sheets, are overlooked. As for fireballs, when one had many observations—in time past up to 400 in one case—we still counted it as one fireball in the table. Also, some of the brief and incomplete reports on single, faint meteors may have been mislaid in handling hundreds of short notes, etc. Among specially active

groups have been the New Haven, Conn.; Bronx, N. Y.; Stetson University, Fla.; the Ohio; the Oregon; and the group near Philadelphia. The war has seriously cut down the number of reports of fireballs from ships at sea. The members we had in Japan have, perhaps temporarily, ceased reporting. Those in New Zealand, now having their own active Meteor Society, no longer report directly to the A.M.S. In this country, groups which are very active in some years become dormant in others. It is impossible to predict when or why this will occur. "Meteor Notes" for the last three months of 1940 gave rather full details of some of our work, naming the observers and giving their rates, etc. In the October number are found the details covering the Perseid campaign near Flower Observatory, and these will not be repeated in the table except to give the total of the 650 meteors observed.

The writer has been pushing his own research on long-enduring meteor trains as his principal work during the last year in meteoric astronomy. He has also initiated consultations with various interested persons to see how the A.M.S. could be organized so that its work would continue in case some contingency should remove him from its direction. Suggestions as to the future of the Society would be welcomed from its members. Most of the members have not paid the dues for 1940. Please send in the annual dues ($1.00) thus saving us time, money, and the trouble of sending out bills.

We welcome the following new members, named in order of their joining:

Miss Dorothy D. McKeon, Rainbow View Farm, Titusville, N. J.
B. P. Brown, 6011 McDonald St., Vancouver, Can.
Miss Dorothy Bradley, Box 7, Burlington, N. C.
S. Daniels, 9050 Clarendon, Detroit, Mich.
Arnold Hartman, 419 Aldrup St., Edwardsville, Ill.
W. A. Borden, 1063 Madison Ave., Birmingham, Mich.
Wm. P. Horton, 19 Pearl St., New Hartford, Conn.
Paul Anderson, Beechwood, Mich.
Chas. Tapscott, 121 W. University, Champaign, Ill.
Cyril A. Lowack, 311 N. Lorel Ave., Chicago, Ill.
Francis Myers, 823 W. 3 St., Erie, Pa.
Prof. Walter S. Houston, 1414 University Ave., Tuscaloosa, Ala.
Gordon Heaton, Box 297, University, Ala.
Miss Lillian Brown, 58 Clayton St., San Francisco, Calif.
Foster D. Bremtom, Agana, Guam.
Marvin Champney, 2126 Vissing Ave., Jackson, Mich.
Brooks Sweeney, 998½ Quarries St., Charleston, W. Va.
Thor Eriksson, 107 E. Cottage St., Haddonsfield, N. J.
Peter Lenert, Jr., Fifield, Wis.

It is hoped to get out a new membership list in the near future. We once more earnestly request members of the A.A.V.S.O. to cooperate by reporting telescopic meteors.

The table is self-explanatory except that in the column "Type" the kind of observation is noted. P means meteors are plotted, C counted, x following means partly plotted, D means described. Telescopic meteors were reported by Mrs. W. M. Kearons, 6; F. J. Kelly, 6; J. W. Simpson, 7; Flower Observatory, 6; E. Loreta, 4; A. Hildom, 3; and W. Callum, 1.

SUMMARY OF OBSERVATIONS RECEIVED SINCE LAST REPORT

New Haven, Connecticut Group—	Nights	No. Meteors	Type	Notes
Anyzeski, V.	2	33	P	
Negle, J. J.	11	144	P	
Neale, Mrs. B. A.	3	11	P	

Purneld, Miss S. L.	1	7		
Martin, H.	4	202	Px	
Short, Miss B.	4	34	P	
Rademacher, Mrs. E. S.	5	156	P	
Miscellaneous		12		
Group Total		(599)		
Oregon Group—				
Pruett, J. H., Eugene, Ore.	1	38	C	
Blaisdell, Mrs. D., Weston, Ore.	1	51	C	
Cox, Mrs. L. B., Yucca, N. D.	1	49	C	
Thompson, Mrs. F., Eugene, Ore.	1	93	C	
Thompson, Miss B., Eugene, Ore.	1	92	C	
Graham, J. W., Salem, Ore.	1	91	C	
Group Total		(414)		
Cooperative Pennsylvania Group, E. Pa.	3	650	Px	
Brockmeyer, C. H., Fredonia, Ky.	1	73	C	
Datz, T., Ebensburg, Pa.	1	44	C	
Dietrich, Wm., Triadelphia, Pa.	1	86	C	
Garrigan, L. N., Springdale, Pa.	1	36	C	
Houston, W., Tuscaloosa, Ala.	1	20	P	
Jamison, A. W., Fayetteville, Ark.	2	29	C	
Knafft, E., Ephrata, Pa.	1	45	C	
Leerman, J., Baltimore, Md.	8	61	C	
Larrabee, Miss L. M., Honolulu, T. H.	1	51	C	
Lewis, C. M., State College, Pa.	1	41	C	
McAlen, J. J., North Cambridge, Mass.	10	206	C	
Scatland, T. L., Philadelphia, Pa.	2	43	C	
Smith, F. W., Thiells, N. Y.	3	16	P	
Strom, Miss D., Dalton, Pa.	1	96	C	
Sundin, H., Jamestown, N. Y.	1	110	C	
Turner, T. W., Quincy, Ill.	1	268	C	
Bronx, New York Group—				
Lambert, G. E., Bronx, N. Y.	36	325	P	
Lambert, Miss M., Bronx, N. Y.	5	152	P	
Lambert, Miss G. E., Bronx, N. Y.	3	21	P	
Four observers	1	194	C	
Miscellaneous		26		
Group Total		(718)		
Stetson University Group, Deland, Fla.	16	293	P	12 observers
Anderson, P., Beechwood, Mich.	5	71	P	
Borden, W. A., Birmingham, Mich.	16	353	P	
Brown, R. P., Vancouver, Canada	4	178	P	
Dole, R. M., Cape Elizabeth, Me.	7	245	Px	
Hardy, C. T., Fremont, Ohio	4	163	C	
Zucher, D., Fremont, Ohio	1	13	C	
Heaton, G., Tuscumbia, Ala.	2	53	P	
Hodge, W. T., Clinton, Miss.	3	56	P	
Haas, W. H., Youngstown, Ohio	6	498	P	4 observers
Huckaba, C. E., Nashville, Tenn.	4	75	P	
Johnson, H. M., Des Moines, Iowa	5	294	Cx	7 observers
Khan, M. A. R., Begumpet Deccan, India	90	1271	P	
Klaas, P. N. Dubuque, Iowa	9	78	P	
Landan, M. S., Louisville, Ky.	4	413	C	8 observers
Loreta, E., Bologna, Italy	10	146	Px	
McArthur, C., North Quincy, Mass.	1	31	P	
Parker, P. O., Ooltewah, Tenn.	1	27	P	
Stone, W. R., Santa Barbara, Calif.	9	28	P	
Topscott, C. T., Champaign, Ill.	16	198	P	
Wallace, Wm., East Cleveland, Ohio	6	138	P	

Brown, C., Blue Bell, Md.	1	52	C	
Caka, J., Flemington, N. J.	3	151	C	
Cole, Mrs. R. M., Bryn Athyn, Pa.	1	42	C	
Smith, Miss L. M., Milton, Pa.	2	41	C	
Truxton, J. D., Collingdale, Pa,	3	258	D	2 observers
Young, Miss L. M., Westminster, Md.	2	57	C	
AAFI, Philadelphia, Pa.	1	123	P	6 observers
Missouri-Southern Illinois Group—				
Friton, E. E., St. Louis, Mo.	4	54	C	
Brueggemann, H. P., St. Louis, Mo.	8	52	C	
Ellison, Miss Mary, Webster Groves, Mo.	2	13	C	
Seune, J. H., St. Louis, Mo.	10	163	C	
Group Total		(282)	in 1939	
Fireballs	143	143		
Miscellaneous	11	43		
Telescopic Meteors	27	27		
Total		9447		

Flower Observatory,
Upper Darby, Pa., February 15, 1941.

Contributions of the Society for Research on Meteorites

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A Statistical Study of the Meteoritic Falls of the World as of Date 1941 January 1

By FREDERICK C. LEONARD *with* BORIS SLANIN*

ABSTRACT

This paper contains 3 tables of statistics, as of date 1941 January 1, for the meteoritic falls of (1) the United States, (2) countries other than the United States, and (3) the continents and the world (1392 falls in all) and a brief discussion of the contents of each table. The data for the tables have been taken from a manuscript catalog of the meteoritic falls of the world now in process of compilation by the writers. The paper ends with a consideration of some 15 factors that favor the recovery of meteorites.

The writers are engaged in the compilation of a catalog of the meteoritic falls[1] of the world, designed to integrate, in as concise a form as possible, the essential information contained in all of the accessible catalogs issued up to date. The publication of this catalog in the near future is contemplated. Meantime, some general statistics concerning meteoritic falls may be made available, with the explanation that, while the data are as accurate as they can be derived at the moment (1941 January 1), they are, nevertheless, only preliminary in character and so are subject to emendation and revision. In preparing the tables that follow, for obvious

reasons only falls (1) that have been *classified* as being at least aërolitic, siderolitic, or sideritic, and only those (2) of which the *place* of fall (or find) has been at least roughly recorded have been included. Hence a few falls, totally undescribed, and several of which the locations are quite unknown—falls that continue, unfortunately, to encumber meteoritical catalogs—have of necessity been excluded from our enumerations and analyses. The number omitted is, however, probably not much in excess of 30 for the whole world.[2]

TABLE 1

THE METEORITIC FALLS OF THE UNITED STATES

	— A. —			— So. —			— Si. —			— TOTAL —		
STATE	*O*	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*
ALABAMA	5	1	6	—	—	—	—	6	6	5	7	12
ARIZONA	1	2	3	—	1	1	—	14	14	1	17	18
ARKANSAS	3	—	3	—	1	1	2	2	4	5	3	8
CALIFORNIA	—	4	4	—	—	—	—	7	7	—	11	11
COLORADO	1	22	23	—	2	2	1	13	14	2	37	39
CONNECTICUT	1	—	1	—	—	—	1	—	1	2	—	2
FLORIDA	—	2	2	—	—	—	—	—	—	—	2	2
GEORGIA	3	1	4	—	—	—	1	12	13	4	13	17
IDAHO	—	—	—	—	—	—	—	2	2	—	2	2
ILLINOIS	2	—	2	—	—	—	—	—	—	2	—	2
INDIANA	2	3	5	—	1	1	—	4	4	2	8	10
IOWA	3	—	3	1	—	1	—	1	1	4	1	5
KANSAS	5	40	45	—	3	3	—	2	2	5	45	50
KENTUCKY	3	—	3	—	2	2	—	14	14	3	16	19
LOUISIANA	—	1	1	—	—	—	—	—	—	—	1	1
MAINE	4	—	4	—	—	—	—	—	—	4	—	4
MARYLAND	2	—	2	—	—	—	—	2	2	2	2	4
MICHIGAN	2	—	2	—	—	—	—	3	3	2	3	5
MINNESOTA	1	1	2	—	—	—	—	1	1	1	2	3
MISSISSIPPI	2	—	2	—	—	—	—	1	1	2	1	3
MISSOURI	5	2	7	—	1	1	—	7	7	5	10	15
MONTANA	—	—	—	—	—	—	—	1	1	—	1	1
NEBRASKA	2	15	17	—	—	—	1	7	8	3	22	25
NEVADA	—	—	—	—	—	—	—	2	2	—	2	2
NEW JERSEY	1	—	1	—	—	—	—	—	—	1	—	1
NEW MEXICO	2	13	15	—	1	1	—	15	15	2	29	31
NEW YORK	1	2	3	—	—	—	—	4	4	1	6	7
NORTH CAROLINA	8	1	9	—	—	—	—	19	19	8	20	28
NORTH DAKOTA	1	—	1	—	—	—	—	3	3	1	3	4
OHIO	2	—	2	—	2	2	—	3	3	2	5	7
OKLAHOMA	2	2	4	—	—	—	—	4	4	2	6	8
OREGON	—	—	—	—	1	1	—	2	2	—	3	3
PENNSYLVANIA	1	—	1	—	—	—	—	5	5	1	5	6
SOUTH CAROLINA	3	—	3	—	—	—	—	4	4	3	4	7
SOUTH DAKOTA	1	—	1	—	—	—	—	2	2	1	2	3
TENNESSEE	2	—	2	—	2	2	1	14	15	3	16	19
TEXAS	6	44	50	—	1	1	—	29	29	6	74	80
UTAH	—	1	1	—	—	—	—	4	4	—	5	5
VIRGINIA	3	—	3	—	—	—	1	6	7	4	6	10
WASHINGTON	1	—	1	—	—	—	—	1	1	1	1	2
WEST VIRGINIA	—	—	—	—	—	—	—	2	2	—	2	2
WISCONSIN	3	—	3	—	—	—	—	4	4	3	4	7
WYOMING	—	4	4	—	1	1	—	4	4	—	9	9
U. S. A.	84	161	245	1	19	20	8	226	234	93	406	499

Table 1 contains the figures for the meteoritic falls of the United States. The first column gives the name of the State (in the last line, that of the United

States); the second, third, and fourth columns, the number observed (O), the number unobserved (U), and the total number (T), for the aërolitic falls (A.); the fifth, sixth, and seventh, corresponding information for the siderolitic falls (So.); the eighth, ninth, and tenth, similar statistics for the sideritic falls (Si.); and the eleventh, twelfth, and thirteenth, the total number of observed falls (O) and of unobserved falls (U) and the grand total number of falls (T), of all 3 kinds together. The final line of the table contains the information for the entire United States.

A multitude of interesting questions is answerable by inspection of the data of the preceding table and those following (nos. 2 and 3). We shall mention here only a few of the most obvious and important conclusions.

(1) While the United States has to its credit by far the largest total number of known[3] falls (499), as well as the largest numbers of (*a*) aërolitic falls (245: 84 obsd.), (*b*) siderolitic falls 20: 1 obsd.), and (*c*) sideritic falls (234: 8 obsd.) of any country in the world (*cf.* Table 2, *post*), only 93, or 18.6%, of these 499 falls were observed; however, with its 93 observed falls, the United States ranks second in this respect only to India (with 108 obsd. falls).

(2) The 6 States having the largest total numbers of falls are: Texas (80: 6 obsd.; 50 A., 1, So., 29 Si.); Kansas (50: 5 obsd.; 45 A., 3 So., 2 Si.); Colorado (39: 2 obsd.; 23 A., 2 So., 14 Si.); New Mexico (31: 2 obsd.; 15 A., 1 So., 15 Si.); North Carolina (28: 8 obsd.; 9 A., 19 Si.); and Nebraska (25: 3 obsd.; 17 A., 8 Si.)—all Western or Southwestern States except North Carolina.

(3) The following 5 States (and also the District of Columbia) have no recorded falls of any kind: Delaware, Massachusetts, New Hampshire, Rhode Island, and Vermont—all New England States except Delaware.

(4) The 6 States having the largest numbers of observed falls are: North Carolina (8: all A.); Texas (6: all A.); Alabama (5: all A.); Arkansas (5: 3 A., 2 Si.); Kansas (5: all A.); and Missouri (5: all A.)—all Southern or Western States.

(5) The 6 States having the largest numbers of unobserved falls are: Texas (74: 44 A., 1 So., 29 Si.); Kansas (45: 40 A., 3 So., 2 Si.); Colorado (37: 22 A., 2 So., 13 Si.); New Mexico (29: 13 A., 1 So., 15 Si.); Nebraska (22: 15 A., 7 Si.); and North Carolina (20: 1 A., 19 Si.)—all Western or Southwestern States except North Carolina.

(6) (*a*) The 6 States having the largest numbers of aërolitic falls are: Texas (50: 6 obsd.); Kansas (45: 5 obsd.); Colorado (23: 1 obsd.); Nebraska (17: 2 obsd.); New Mexico (15: 2 obsd.); and North Carolina (9: 8 obsd.)—all Western or Southwestern States except North Carolina. (*b*) The 6 States having the largest numbers of observed aërolitic falls are: North Carolina (8); Texas (6); Alabama (5); Kansas (5); Missouri (5); and Maine (4)—all Southern or Western States except Maine. (*c*) The 5 States having the largest numbers of unobserved aërolitic falls are: Texas (44); Kansas (40); Colorado (22); Nebraska (15); and New Mexico (13)—all Western or Southwestern States.

(7) (*a*) The 5 States having 2 or more siderolitic falls are: Kansas (3); Colorado (2); Kentucky (2); Ohio (2); and Tennessee (2)—all Western or Southern States except Ohio. None of the aforementioned 11 falls was witnessed. (*b*) Iowa is the only State having an observed siderolitic fall. (*c*) The only State having as many as 3 unobserved siderolitic falls is obviously Kansas.

(8) (*a*) The 7 States having the largest numbers of sideritic falls are: Texas

(29: none obsd.); North Carolina (19: none obsd.); New Mexico (15: none obsd.); Tennessee (15: 1 obsd.); Arizona (14: none obsd.); Colorado (14: 1 obsd.); and Kentucky (14: none obsd.)—all Western or Southern States. (*b*) Arkansas is the only State having as many as 2 observed sideritic falls. (*c*) The 6 States having the largest numbers of unobserved sideritic falls are: Texas (29); North Carolina (19); New Mexico (15); Arizona (14); Kentucky (14); and Tennessee (14)—all Western or Southern States (*cf.* [*a*], same par.).

It is interesting to compare the present conclusions regarding the falls of the United States and North America (see also Tables 2 and 3, *post*) with the conclusions reached by O. C. Farrington in the introduction to his "Catalogue of the Meteorites of North America, to January 1, 1909,"[4] and to note how the information that has accumulated during the past 32 years has necessitated modification of many of the earlier conclusions of Farrington.

TABLE 2

THE METEORITIC FALLS OF COUNTRIES OTHER THAN THE UNITED STATES

	— A. —			— So. —			— Si. —			— TOTAL —		
COUNTRY	*O*	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*
AFRICA (MISC.)[1]	11	1	12	1	—	1	—	3	3	12	4	16
ALGERIA	3	1	4	—	—	—	—	3	3	3	4	7
ARABIA	1	3	4	—	—	—	—	3	3	1	6	7
ARGENTINA	5	5	10	—	2	2	—	3	3	5	10	15
ASIA (MISC.)[2]	14	—	14	1	—	1	—	1	1	15	1	16
AUSTRALIA[3]	6	23	29	—	8	8	—	54	54	6	85	91
AUSTRIA	3	1	4	—	—	—	—	—	—	3	1	4
BELGIUM	3	—	3	—	—	—	—	—	—	3	—	3
BOLIVIA	—	—	—	—	1	1	—	2	2	—	3	3
BRAZIL	7	2	9	—	—	—	1	6	7	8	8	16
BRITISH ISLES	16	1	17	—	—	—	1	1	2	17	2	19
ENGLAND & WALES	8	—	8	—	—	—	1	—	1	9	—	9
IRELAND	5	—	5	—	—	—	—	1	1	5	1	6
SCOTLAND	3	1	4	—	—	—	—	—	—	3	1	4
CANADA	4	2	6	—	1	1	—	12	12	4	15	19
CENTRAL AM. (MISC.)[4]	1	—	1	—	—	—	—	2	2	1	2	3
CHILE	—	5	5	—	5	5	—	33	33	—	43	43
CHINA	4	—	4	1	—	1	—	—	—	5	—	5
CZECHOSLOVAKIA	14	—	14	—	—	—	1	8	9	15	8	23
ESTONIA	2	—	2	—	—	—	—	1	1	2	1	3
EUROPE (MISC.)[5]	4	—	4	—	—	—	1	—	1	5	—	5
FINLAND	4	2	6	1	—	1	—	—	—	5	2	7
FRANCE[6]	53	2	55	—	—	—	—	1	1	53	3	56
FRENCH W. AFRICA	4	—	4	—	—	—	1	2	3	5	2	7
GERMANY	21	2	23	—	3	3	2	6	8	23	11	34
HOLLAND	3	—	3	—	—	—	—	—	—	3	—	3
HUNGARY	5	—	5	—	—	—	—	1	1	5	1	6
INDIA	102	2	104	2	1	3	4	—	4	108	3	111
ITALIAN SOMALILAND	2	—	2	—	—	—	—	1	1	2	1	3
ITALY	17	—	17	—	—	—	1	—	1	18	—	18
JAPAN	22	3	25	—	—	—	4	5	9	26	8	34
JAVA	6	—	6	—	—	—	1	1	2	7	1	8
LATVIA	5	—	5	—	—	—	—	—	—	5	—	5
LITHUANIA	5	—	5	—	—	—	—	—	—	5	—	5
MEXICO	9	—	9	—	1	1	1	44	45	10	45	55
N. AMER. (MISC.)[7]	1	—	1	—	1	1	—	4	4	1	5	6
NORWAY	6	—	6	—	1	1	—	1	1	6	2	8
PHILIPPINE ISLANDS	3	—	3	—	—	—	—	—	—	3	—	3
POLAND	4	—	4	1	—	1	—	1	1	5	1	6
PORTUGAL	3	1	4	—	—	—	—	—	—	3	1	4

Country	— A. —			— So. —			— Si. —			— Total —		
	O	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*
Rumania	6	1	7	—	—	—	—	—	—	6	1	7
S. Amer. (Misc.)[8]	1	1	2	—	—	—	—	1	1	1	2	3
S. W. Africa	1	—	1	—	—	—	—	3	3	1	3	4
Spain	20	2	22	2	—	2	2	2	4	24	4	28
Sweden	6	1	7	—	—	—	—	1	1	6	2	8
Switzerland	5	—	5	—	—	—	—	1	1	5	1	6
Turkey	4	1	5	—	—	—	1	—	1	5	1	6
Union of S. Africa	14	4	18	—	1	1	3	12	15	17	17	34
U. S. S. R.	67	11	78	—	5	5	4	22	26	71	38	109
Russia	52	9	61	—	2	2	2	10	12	54	21	75
Siberia	15	2	17	—	3	3	2	12	14	17	17	34
Yugoslavia	6	—	6	—	—	—	1	—	1	7	—	7
Gen. Misc.[9]	2	1	3	1	—	1	—	—	—	3	1	4
All Countries except the U.S.A.	505	78	583	10	30	40	29	241	270	544	349	893

Notes to Table 2

[1] Includes Anglo-Egyptian Sudan, Cameroon, Egypt (2), Ethiopia, Kenya, Morocco (2), Nigeria (2), Nyasaland Protectorate (2), Rhodesia, Tanganyika Territory (2), and Tunisia. [The figure in parentheses, following the name of the place, is the total number of falls, if this is greater than 1.]

[2] Includes Burma (2), Ceylon, French Indo-China (4), Iraq (2), Korea (3), Mongolia, Persia, and Syria (2).

[3] Includes New Zealand (4) and Tasmania (3).

[4] Includes Costa Rica, Guatemala, and Honduras.

[5] Includes Balearic Islands, Bulgaria (2), Denmark, and Greece.

[6] Includes Corsica.

[7] Includes Alaska (2), Cuba, Greenland, Hawaiian Islands, and Jamaica.

[8] Includes Colombia and Paraguay (2).

[9] Includes the Antarctic regions, Mauritius, New Caledonia, and New Guinea.

The arrangement of Table 2, for the meteoritic falls of countries other than the United States, is exactly like that of Table 1. The final line of the table gives the figures for all of these countries combined. The following conclusions are apparent from the table.

(1) The 6 countries having the largest total numbers of falls are: India (111: 108 obsd.; 104 A., 3 So., 4 Si., as against 499: 93 obsd. for the U. S.); the U.S.S.R. (109: 71 obsd.; 78 A., 5 So., 26 Si.; Russia alone, 75: 54 obsd.; 61 A., 2 So., 12 Si.); Australia (91: 6 obsd.; 29 A., 8 So., 54 Si.); France (56: 53 obsd.; 55 A., 1 Si.); Mexico (55: 10 obsd.; 9 A., 1 So., 45 Si.); and Chile (43: none obsd.; 5 A., 5 So., 33 Si.).

(2) The 6 countries having the largest numbers of observed falls are: India (108 [this is the largest number of observed falls for any country in the world]: 102 A., 2 So., 4 Si.); the U.S.S.R. (71: 67 A., 4 Si.; Russia alone, 54: 52 A., 2 Si.); France (53: all A.); Japan (26: 22 A., 4 Si.); Spain (24: 20 A., 2 So., 2 Si.); and Germany (23: 21 A., 2 Si.).

(3) The 6 countries having the largest numbers of unobserved falls are: Australia (85: 23 A., 8 So., 54 Si., as against 406 for the U.S.); Mexico (45: 1 So., 44 Si.); Chile (43: 5 A., 5 So., 33 Si.); the U.S.S.R. (38: 11 A., 5 So., 22 Si.; Russian alone, 21: 9 A., 2 So., 10 Si.); the Union of South Africa (17: 4 A., 1 So., 12 Si.); and Canada (15: 2 A., 1 So., 12 Si.).

(4) (*a*) The 7 countries having the largest numbers of aërolitic falls (*i.e.*, 22 or more) are India (104: 102 obsd., the latter number constituting another "world's record"); the U.S.S.R. (78: 67 obsd.; Russia alone, 61: 52 obsd.); France (55:

53 obsd.); Australia (29: 6 obsd.); Japan (25: 22 obsd.); Germany (23: 21 obsd.); and Spain (22: 20 obsd.). (*b*) The 6 countries having the largest numbers of observed aërolitic falls are: India (102); the U.S.S.R. (67; Russia alone, 52); France (53); Japan (22); Germany (21); and Spain (20). (*c*) The 5 countries having the largest numbers of unobserved aërolitic falls are: Australia (23, as against 161 for the U.S.); the U.S.S.R. (11; Russia alone, 9); Argentina (5); Chile (5); and the Union of South Africa (4).

(5) (*a*) The 3 countries having 5 or more siderolitic falls (all unobsd.) are: Australia (8, as against 20: 1 obsd. for the U.S.); Chile (5); and the U.S.S.R. (5; Siberia alone, 3). (*b*) The only countries having as many as 2 observed siderolitic falls are India and Spain. (*c*) The 4 countries having 3 or more unobserved siderolitic falls are: Australia (8, as against 19 for the U.S.); Chile (5); the U.S.S.R. (5; Siberia alone, 3); and Germany (3); *cf.* (*a*), same par.

(6) (*a*) The 6 countries having the largest numbers of sideritic falls are: Australia (54: none obsd., as against 234: 8 obsd. for the U.S.); Mexico (45: 1 obsd.); Chile (33: none obsd.); the U.S.S.R. (26: 4 obsd.; Siberia alone, 14: 2 obsd.); the Union of South Africa (15: 3 obsd.); and Canada (12: none obsd.). (*b*) The 4 countries having more than 2 observed sideritic falls are: India (4, as against 8 for the U.S.); Japan (4); the U.S.S.R. (4; Russia and Siberia, each 2); and the Union of South Africa (3). (As is clear from the foregoing figures [see also (4) (*b*), immediately preceding] and the data of Table 1, *ante*, the United States ranks second among the countries of the world with its number of observed aërolitic falls [84] and first with its number of observed sideritic falls [8].) (*c*) The 6 countries having the largest numbers of unobserved sideritic falls are Australia (54, as against 226 for the U.S.); Mexico (44); Chile (33); the U.S.S.R. (22: Siberia, 12; Russia, 10); Canada (12); and the Union of South Africa (12). (The United States has nearly half [234] of the sideritic falls of the world [504] and almost half [226] of the unobserved sideritic falls [467] [*cf.* Table 3, *post*].)

TABLE 3

THE METEORITIC FALLS OF THE CONTINENTS AND OF THE WORLD

	— A. —			— So. —			— Si. —			— TOTAL —		
CONTINENT	*O*	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*	*O*	*U*	*T*
AFRICA	35	6	41	1	1	2	4	24	28	40	31	71
AUSTRALIA[1]	5	20	25	—	8	8	—	54	54	5	82	87
EURASIA	425	33	458	8	10	18	22	55	77	455	98	553
ASIA[2]	161	11	172	4	4	8	11	21	32	176	36	212
EUROPE[2]	264	22	286	4	6	10	11	34	45	279	62	341
NORTH AMERICA[3]	98	163	261	1	22	23	9	288	297	108	473	581
OCEANIA[4]	10	—	10	1	—	1	1	1	2	12	1	13
SOUTH AMERICA	13	13	26	—	8	8	1	45	46	14	66	80
MISC.[5]	3	4	7	—	—	—	—	—	—	3	4	7
THE WORLD	589	239	828	11	49	60	37	467	504	637	755	1392

NOTES TO TABLE 3

[1] The 4 New Zealand falls have not been included in the figures for continental Australia, but the 3 Tasmanian falls have been.

[2] The imaginary line between Europe and Asia is, for the purpose of this paper, defined as running from the Kara Sea along the Kara River, the Ural Mountains, and the Ural River, through the Caspian Sea, and along the boundary between Transcaucasia and Turkey, to the Black Sea.

[3] Includes Central America (3) [Continental North America is considered as ex-

tending to the boundary between Panama and Colombia], Cuba, Greenland, and Jamaica.

[4] Includes Java (8), New Caledonia, New Guinea, and Philippine Islands (3).

[5] Includes the Antarctic regions, Hawaiian Islands, Mauritius, and New Zealand (4).

The arrangement of Table 3, for the meteoritic falls of the continents and of the world, is identical with that of the 2 foregoing tables. The last line gives the information for the entire world. The following self-evident conclusions from the data of this table are noteworthy.

(1) The continent having the largest total number of falls is North America (581: 108 obsd.; 261 A., 23 So., 297 Si.).

(2) The continent having the smallest total number of falls is Africa (71: 40 obsd.; 41 A., 2 So., 28 Si.).

(3) The continent having the largest number of observed falls is Eurasia (455: 425 A., 8 So., 22 Si.) or Europe alone (279: 264 A., 4 So., 11 Si.).

(4) The continent having the smallest number of observed falls is Australia (5: all A.).

(5) The continent having by far the largest number of unobserved falls is North America (473 [as against only 98 for Eurasia: 33 A., 10 So., 55 Si.]: 163 A., 22 So., 288 Si.).

(6) The continent having the smallest number of unobserved falls is Africa (31: 6 A., 1 So., 24 Si.).

(7) (*a*) The continent having the largest number of aërolitic falls is Eurasia (458: 425 obsd.) or Europe alone (286: 264 obsd.). (*b*) The continent having the largest number of observed aërolitic falls is Eurasia (425) or Europe alone (264). (*c*) The continent having the largest number of unobserved aërolitic falls is North America (163).

(8) (*a*) The continent having the smallest number of aërolitic falls is Australia (25: 5 obsd.; but South America has only 26, of which 13 were obsd.). (*b*) The continent having the smallest number of observed aërolitic falls is Australia (5). (*c*) The continent having the smallest number of unobserved aërolitic falls is Africa (6).

(9) (*a*) The continent having the largest number of siderolitic falls is North America (23: 1, only, obsd.). (*b*) The continent having the largest number of observed siderolitic falls is Eurasia (8) or Asia and Europe separately (each 4). (*c*) The continent having the largest number of unobserved siderolitic falls is North America (22).

(10) (*a*) The continent having the smallest number of siderolitic falls is Africa (2: 1 obsd.). (*b*) Both Australia and South America have no observed siderolitic falls. (*c*) The continent having the smallest number of unobserved siderolitic falls is Africa (1).

(11) (*a*) The continent having by far the largest number of sideritic falls is North America (297: 9, only, obsd., as against 77 for Eurasia, of which as many as 22 are reported to have been witnessed). (*b*) The continent having the largest number of observed sideritic falls is Eurasia (22) or Asia and Europe separately (each 11). (*c*) The continent having the largest number of unobserved sideritic falls is of course North America (288).

(12) (*a*) The continent having the smallest number of sideritic falls is Africa (28: 4 obsd.). (*b*) Australia has no observed sideritic fall. (*c*) The continent

having the smallest number of unobserved sideritic falls is Africa (24) or Asia (21), if considered apart from Eurasia.

(13) (*a*) The total number of aërolitic falls of the world is 828, of which 589, or 71.1%, were observed. (*b*) The total number of siderolitic falls is 60, of which 11, or 18.3%, were observed. (*c*) The total number of sideritic falls is 504, of which 37, or 7.3%, were observed. (*d*) The grand total number of the meteoritic falls of the world is 1392, of which 637, or 45.8%, were observed.

(14) (*a*) The aërolitic falls constitute 59.5%, (*b*) the siderolitic falls, 4.3%, and (*c*) the sideritic falls, 36.2%, of all the falls of the world.

In conclusion, we shall consider synoptically the principal factors that favor the recovery of meteorites from a given area of the Earth's surface. If meteorites fall at random, more meteorites should be recovered from an area *A* than from an area *B of the same size*, if ("other things being equal")—

(1) More meteorites have (*a*) fallen and (or) (*b*) been seen to fall in *A*.

(2) Larger meteorites have (*a*) fallen and (or) (*b*) been seen to fall in *A*.

(3) Meteorites have (*a*) fallen and (or) (*b*) been seen to fall more recently in *A*.

(4) The meteorites that have fallen in *A* are intrinsically more resistant to disintegration. (A siderite is usually more resistant than an aërolite.)

(5) (*a*) The climate and soil of *A* are more conducive to the *preservation* of meteorites (*e.g.*, the climate of *A* is drier and the soil is less likely to cause disintegration of meteorites). (*b*) The weather and climate of *A* are more favorable to the *recovery* of meteorites. (More meteorites should be found in good weather and in a fine climate than in the reverse.)

(6) The meteorites that have fallen in *A* lie nearer the surface of the ground. (A meteorite lying on the surface of the ground is obviously more likely to be found than one buried at any depth below the surface.)

(7) The meteorites in *A* have properties (*e.g.*, magnetism) that render them more easily discoverable by instrumental means (such as meteorite-detecting devices, "magnetic rakes," simple magnets, *etc.*).

(8) *A* is more accessible.

(9) The topography of *A* is of such a character as to render the detection of meteorites easier there than in *B*, because (*a*) they are more accessible within the region itself; (*b*) they are less concealed; and (*c*) they are more in contrast to their surroundings. (Siderites are generally more easily recognizable as meteorites than are aërolites, while aërolites are more readily distinguishable as such in places where terrestrial stones are scarce.)

(10) There is (or has been) more observational evidence of the fall of meteorites in *A* (such as brilliant meteors and meteoric trains; meteoritic clouds, sounds, *etc.*).

(11) There is more superficial evidence of meteoritic impact in *A* (*e.g.*, meteoritic craters and damage done to natural objects and to property by falling meteorites).

(12) *A* has a greater population (both permanent and transient).

(13) The dispersion and distribution of the population of *A* within the area (as a result of both residence and travel) coincide more nearly with the dispersion and distribution of the meteorites.

(14) The population of *A* is more intelligent and (or) more highly educated. (*a*) The population of *A* manifests a greater interest in or curiosity about natural objects, for superstitious, religious, or intellectual reasons. (*b*) It is more aware of the value of meteorites, either (*i*) for use as artifacts or (*ii*), as scientific specimens for sale and preservation, because it is more "meteorite-conscious," being better informed or having received more publicity on the subject. (Superstitious, intelligent, educated, and mercenary people all are apt to collect and save specimens that appeal to them as being interesting or valuable.)

(15) The inhabitants of *A* are engaged in occupations that tend to lead to their detection of meteorites. (Outdoor people generally and, in particular, vacationers, hunters, miners,[5] cattlemen, farmers, and—last but not least!—collectors and meteoriticists are evidently more apt to discover meteorites than are other persons.)

Indubitably several of the aforementioned factors, both natural and human, have been in operation wherever and whenever meteorites have been found.

Of the preceding points, nos. (2*a*), (4), (7), (9*c*), (11, *craters* at least), and (14*b*, *i*) seem to indicate generally the discovery of siderites, while nos. (1*a*), (1*b*), (2*b*), (3*a*), (3*b*), and (10) may betoken commonly the recovery of aërolites (if aërolites are more numerous than siderites and if more aërolites than siderites are observed to fall, as has been the case).

NOTES

*The writing of the paper is the work of the senior author and the assembly of the tables, that of the junior author.

[1] The term *fall* is used in the sense in which it is defined in *C.S.R.M.*, **1**, No. 3, 2, last par.; *P. A.*, **45**, 47, first par., 1937.

[2] Hammond's *Modern Illustrated Atlas of the World*, De Luxe Ed., Garden City Publishing Co., Inc., Garden City, N. Y., 1937-38, has been employed generally in the preparation of this paper and its accompanying tables as our authority on geographical matters. The geographical "epoch" (in the astronomical sense of this term) is, accordingly, 1938.

[3] The word *known* will not be repeated hereafter, where it is obviously understood.

[4] *Mem. Nat. Acad. Sci.*, **13**, 7-16, 1915.

[5] *Cf.* L. La Paz, *C.S.R.M.*, **2**, No. 3, 172-88; *P. A.*, **48**, 157-65, 205-12, 1940, who has shown that the meteoritic concentration in the southern Appalachian region of the United States is explicable mainly by the extensive amount of small-scale placer-mining that has been prosecuted in that area.

Collecting Small Meteoritic Particles

By H. H. NININGER

ABSTRACT

The importance of the showering of small particles associated with meteoritic falls is emphasized and some of the difficulties encountered by those who attempt to investigate the phenomenon are pointed out. A trial search for specimens at the site of the Holbrook, Arizona, fall of 1912 July 19, made in April, 1940, is described. 3 small aërolites with a combined weight of 0.0948 g., which were recovered in the course of the search, are recorded. The method of collecting specimens is described and a plan for obtaining a quantitative estimate of the total amount of material that fell in this shower is outlined.

April 15, 1940, will stand out, always, as a red-letter day in the lives of three ardent students of meteorites. On that day, after painful hours of search in a raging sand-storm on the Arizona desert along the Little Colorado River, some 7

miles east of Holbrook, at the railroad station of "Arntz," in Navajo County, these three workers were rewarded with success in a search for an ingredient of meteoritic showers never before collected. For many years, the writer has been convinced that an important aspect of every shower of meteorites is the rain of small particles comparable in size to grains of sand and gravel. In 1932, he met, for the first time, with persons who had actually felt such showering. However, all efforts to collect *bona fide* specimens of this material were fruitless until the month of April, 1940. A little reflection upon the problem will at once indicate the difficulties which face one in the search for such particles. First, unless one has actually felt, or has at least heard, the fall of these particles, he can have but little idea as to the location in which to search for them. Ordinary meteorites, such as those from which the specimens in our museums have come, disintegrate at stratospheric elevations, usually from 8 to 15 miles above the soil. The ponderable masses that escape this disintegration continue their courses to the ground in directions which diverge from that followed by the parent mass during its luminous flight and which are inclined more to the vertical. Small particles, on the other hand, are drifted by wind currents, concerning the direction of which we know nothing by the methods (or the lack of methods) used in studying meteoritic showers today. The showers of the larger stones scatter over areas from 5 to 50 square miles in extent, while the rain of small particles must certainly spread much more widely. This rain of meteoritic "gravel" may lie to the east, west, north, or south, depending upon the directions and velocities of wind currents encountered, the trajectory of the invading parent mass, and the elevation of the point of final disintegration. These factors are not known, usually, even approximately, until weeks or months after the fall has occurred; so one is confronted in reality by an area of several hundred square miles in which to choose his place of search! One could well hope that some day he might be fortunate in meeting dependable witnesses of such a showering. There have been a few such cases; but either too much time had elapsed, or the condition of the soil, or the growth of vegetation had frustrated our efforts to recover actual particles. Distance and consequent expense of operations, also, have proved to be serious obstacles, so that our attempts have been limited largely to brief stops in connection with expeditions whose objectives were more tangible. In 1939, we covered several considerable areas, both at Holbrook and at Plainview, Texas, with our magnetic rake (see *Year Book, Am. Phil. Soc.*, p. 268, 1939), but we secured only a few stones, the smallest of which weighed about 0.2 g.

On April 13, 1940, Mrs. Nininger and I were at Winslow, Arizona, where we were met by Dr. Frederick C. Leonard of the Department of Astronomy of the University of California at Los Angeles. The following day was spent at the great Meteorite Crater in Coconino County, 20 miles to the west. On Monday, the three of us drove eastward some 40 miles from Winslow to the site of the Holbrook aërolitic shower of 1912 July 19, 7:15 P.M. Here, Dr. Leonard was eager to experience the thrill of finding a specimen that had been missed in the diligent search which years ago yielded more than 14,000 stones varying in weight from 0.1 g. to 6665 g. (and a later one, conducted by the writer, which had yielded an additional 2000 specimens). A 40-mile wind was whipping up a severe dust- and sand-storm, which made a visual search almost impossible; consequently, all efforts were soon directed to a magnetic search for small particles, which was my chief interest. Dr. Leonard and I carried *"alnico"* magnets. Mine was the 3-inch size and Dr. Leonard's, the 1¼-inch. The terrain was heavily sprinkled with small gravel, much of which was dark in color. One ingredient of this terrestrial deposit was basaltic

and a portion of this was magnetic. The magnetic material rendered our task even more difficult, especially in view of the blinding dust-storm. After a prolonged, unsuccessful search of the undisturbed soil, we turned our attention to ant hills, where the large red ants had piled up mounds of gravel and sand. The magnets were dragged slowly and systematically over these mounds and all adhering particles were carefully inspected on the spot. When finally the fury of the storm rendered further search impracticable, we took our small collection of suspected (magnetic) material and drove back to our respective quarters in Winslow, feeling pretty certain that our efforts had not been in vain. The material was painstakingly examined and, among the particles that had been secured by means of the larger magnet, were found 3 perfect little aërolites, measuring respectively 2×2×3 mm., 2×2.5×3 mm., and 2.5×3×4.8 mm. Each of these tiny stones was completely, or almost completely, inclosed in the usual fusion crust, which was in a few spots stained by iron-rust surrounding slight protrusions which evidently marked the locations of nickel-iron grains. At one place where the fusion crust was not quite complete, the gray interior of the little aërolite was clearly visible. At a later date, the specimens were weighed, both together and separately. Their combined weight was found to be 0.0948 g.! Individually, their weights were determined as 0.0518 g., 0.0248 g., and 0.0183 g., respectively. The smallest Holbrook specimen that I have found recorded in any of the catalogs weighs 0.1 g. Such specimens were reported by A. F. Foote and also by the American Museum of Natural History. Moreover, several Holbrook stones of this size are in the Nininger collection, Dr. Leonard's collection, and some others.

The fact that these recently recovered specimens are the smallest meteorites on record is not in itself important; but the further fact that they furnish final proof of the rain of fine particles in connection with showers of meteoritic stones marks the beginning of a new and important phase in the study of meteorites—a phase which, in the writer's opinion, will prove to be of far greater importance, eventually, than the collection and study of meteorites as museum specimens and as subjects for analysis. Before any reliable quantitative records of meteoritic falls can be obtained, both the extent and the intensity of this rain of small particles will have to be determined. The vast "dust" clouds produced at the end of the luminous flights of meteorites doubtless mark the point of origin of these small particles. In company with these gravel-sized particles are surely produced still finer ones. Much of this finest material is in the form of dust. For the most part, these finest ingredients will have to await preparations for atmospheric exploration immediately following falls. But a careful survey of areas showered by finer and finer particles, beginning with grains of the size reported on in this paper, will lead probably to the discovery of meteoritic deposits on and in the soil. To study effectively this aspect of meteoritics will require most diligent application and great patience; but its geological implications are readily appreciated when one reflects that the dust clouds produced total usually many cubic miles in volume and often appear comparable in density to cumulus clouds of water vapor, while an average of one such particle as we collected to each area of 5 square feet amounts to a mass of nearly 2 tons on an area of 10 square miles!

Almost 30 years have elapsed since the Holbrook fall occurred. Obviously, any adequate investigation should have been made immediately after that shower took place. We look forward to the time when such an opportunity may present itself again. We propose to make a quantitative exploration of the ant mounds at Arntz and to use the results as a basis for calculations regarding the extent and

the intensity of the shower of small particles which evidently constituted part of the Holbrook shower of aërolites.

First Notice of the Eighth Meeting of the Society

By gracious invitation of the three leading educational institutions of Flagstaff, Arizona—the Museum of Northern Arizona, the Arizona State Teachers College, and the Lowell Observatory—and by action of the Council, the Society will hold its Eighth Meeting in that city on June 23, 24, and 25, 1941. A prominent feature of this meeting will be an excursion to the great Canyon Diablo Meteorite Crater, some forty miles east of Flagstaff.

The Eighth Meeting will be an electoral meeting—for the 1941-45 term of the Council. In accordance with Art. 3, Sect. 5 of the Constitution of the Society, the Council hereby announces that a President, *three* Vice-Presidents, a Secretary, a Treasurer, an Editor, and *seven* Councilors are to be elected for the ensuing term. (Under the Constitution, the retiring President, Dr. Nininger, will be, *ex officio*, the *eighth* Councilor; Vice-Presidents Foshag and Wylie are ineligible for reëlection to the Council as either *Vice-Presidents* or *Councilors;* and Councilors Butler, Moulton, Nichols, and Whitney are ineligible for reëlection to the Council, *except as officers,* for the 1941-45 term, since each of the aforesaid Vice-Presidents and Councilors will have served two terms (eight years) in his present position.)

The Secretary wishes to call the attention of fellows to the following excerpt from Art. 3, Sect. 3 of the Constitution: "The members of the Council, other than the *ex-officio* Councilor, shall be elected by ballot at an electoral meeting of the Society. At least three months prior to the date of such a meeting, the Council shall nominate one candidate for each position in the Council that shall be filled by the next following election. A nomination for any such position may be made also *by any six fellows of the Society in good standing,* if signed by them, transmitted to the Secretary, and received by him not later than three months prior to the date of the meeting." Nominations for members of the Council for the 1941-45 term, by fellows of the Society, will, accordingly, be received by the Secretary until March 26, 1941.

ROBERT W. WEBB, *Secretary*

VARIABLE STARS

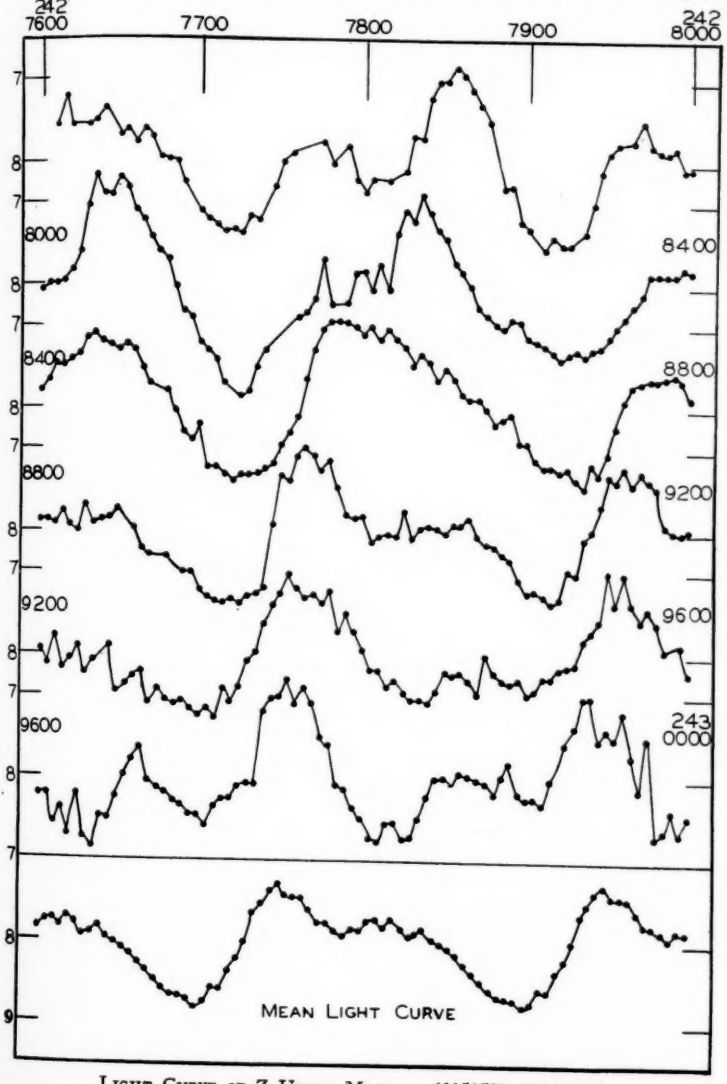
Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

An "Irregular" Long-Period Variable: The variable star Z Ursae Majoris, 115158, has been on the A.A.V.S.O. observing list since 1934. It was placed there at the request of the spectroscopic observers of the Dominion Astrophysical Observatory, who were desirous of having its light curve observed contemporaneously with its spectral changes.

The variable was discovered by E. S. King from the peculiarities noted in its spectrum, which was announced to be of Type III, having also the lines Hδ and Hγ bright; the star was found to have a range in variation of at least 1.5 magnitudes, which would place it among the long-period variables having the shorter periods and smaller ranges in variation. The normal long-period variables have periods averaging 275 days, and ranges of four or more magnitudes.

Various periods, including those of 100 days, and of twice that amount, have been assigned to the star. Schneller's catalogue gives the period as 198 days, a



LIGHT CURVE OF Z URSAE MAJORIS (115158) 1934-1940

photographic range in magnitude from 8.4 to 10.2, a spectrum M6e, and the star is classified there as an RV Tauri-type variable.

In the year 1928, B. P. Gerasimovič made a photographic study of the star from Harvard plates covering the years 1900 to 1921, and concluded that it belonged to the RV Tauri-type, and that it might well serve as the connecting link between ordinary long-period variables and Cepheids.

A plot of the A.A.V.S.O. observations, under five-day means, confirms the period of 198 days and shows a mean visual range of 1.5 magnitudes—7.3 to 8.8—but does not confirm its designation as an RV Tauri-type variable, if we assume that an RV Tauri star undergoes, in general, a reversal of deep and shallow minima, for such does not appear to be the case for Z Ursae Majoris, at least as shown by the observations here discussed.

The light curve shows irregularities not usually found in ordinary long-period variables, especially those with periods decidedly greater than 200 days, but it does resemble some of the curves found for those with periods under 200 days, and with ranges of less than two magnitudes.

There is a fair accordance of the intervals between minima and the shape of the light curve at minimum, but there is a wide diversity in the intervals between maxima and the form of curve at phases other than minimum. These features are clearly shown in the figure, which represents the observed light curve from 1934 to 1940, inclusive, with a mean light curve indicated in the lower portion of the figure.

Observed dates of minima, derived by superposition of the individual curves upon the mean light curve, are given in the table. The mean period, as derived from these observed dates, is 197.2 days, with an average deviation of 6 days for the individual cycles.

J.D. Min.	Cycle	Dev.	Mag. Min.	J.D. Min.	Cycle	Dev.	Mag. Min.
2427724	194	+03	8.8	2428916	196	+01	8.9
7918	210	−13	9.0	9112	192	+05	8.8
8128	196	+01	9.3	8304	198	−01	8.7
8324	205	−08	8.8	9502	203	−06	8.5
8529	202	−05	8.9	9705	188	+09	8.5
8731	185	+12	8.8	9893	..	..	8.3

A comparison of the individual light curves with the mean light curve shows all sorts of variations in form as the light changes progress from minimum through maximum, back to minimum. In fact a mean light curve has very little significance for this star, except possibly at and near minimum phase. The average deviation, corresponding to the amount of scattering, of the individual curves is large near maximum phase, approximately half a magnitude, while at and near minimum phase, it amounts to only a quarter of a magnitude.

Like several other stars of this type, there seems to be evidence of the working of two or more periods. Miss Frida Palmer has suggested a combination of two periods, one of 198 days and the other of 2600 days. These A.A.V.S.O. observations do not extend over a sufficient number of years to check this proposed 2600 day period, but it might be well to study the older visual observations to see if this value is confirmed.

Such an irregular variable as Z Ursae Majoris requires constant attention on the part of observers, visual as well as spectroscopic. Perhaps homogeneous observations over many years may lead us to a solution as to how, when and why the peculiar waves, or secondary fluctuations, in the light curves makes their appearance in this star.

A Group of Peculiar Cepheids: It is a well-established fact that the forms of

light curves of most Cepheid variables are closely related to their periods: the progression in form and in the presence and position of humps is so well marked that the period can often be inferred from the shape of the curve alone.

Dr. C. Payne-Gaposchkin points out that a few stars have long been known to be exceptional in this respect. The well-known variable, W Virginis, which has a period of about 17 days, shows a light curve quite unlike that of the typical seventeen day Cepheid. The peculiarity of W Virginis is not confined to the shape of its light curve; the period is variable, the spectrum is peculiar in showing bright lines at and after minimum, and the lag between light maximum and velocity minimum is more than a tenth of the period. Furthermore, W Virginis is at galactic latitude 57°—exceptionally high for a Cepheid, since bright Cepheids are usually found near to the Milky Way.

Recently Dr. Joy, at Mount Wilson, has shown that another star bears a strong resemblance to W Virginis. The so-called "Barnard's variable" in the globular cluster Messier 2 shares all the physical peculiarities of W Virginis. The light curve is of similar shape; bright lines are found at minimum and on the rising branch of the light curve; and a similar lag between light and velocity curve is found for both stars. The period of Barnard's variable is seventeen and three quarter days, almost equal to that of W Virginis. It seems certain that the two stars have a close physical similarity. Perhaps the most striking features of the comparison is the presence of bright lines, almost unknown in the spectra of normal Cepheids.

Another star, recently rediscussed at Harvard, may well be closely related to the two stars just mentioned. The well-known variable RU Camelopardis has many features that recall the other two—especially W Virginis. The period is strongly variable. The light curve is abnormal for the period (22 days) and very like those of the two stars just mentioned. The spectral changes and velocity curve have also much in common—again there is a lag between light and velocity curves, and again bright lines are found near minimum and persist over the rising branch of the light curve, to disappear at maximum. The most striking peculiarity of RU Camelopardalis is that the spectrum varies from type K at maximum to type R at minimum; the variation is evidently intrinsic and not geometrical, and is probably occasioned by the formation of carbon compounds in the envelope with falling temperature. A similar phenomenon is found in some normal Cepheids, such as Z Scuti and SV Vulpeculae, with the formation of titanium oxide bands at maximum. The inference is that RU Camelopardalis, like R Coronae Borealis, is a star whose atmosphere is unusually rich in carbon. It is tempting, though as yet unproven, to suggest that the abnormality in light curve is related to differences of composition, and that W Virginis, if closely studied, might reveal spectroscopic differences from normal Cepheids with spectra of Class G (to which it is assigned). It is possible that VX Cygni, with period and spectrum not unlike RU Camelopardalis, is a star that should also be classed with the other three.

Observers and Observations received during January, 1941: The effect of the war abroad, coupled with cloudy conditions which appear to have prevailed over many sections of this country in January, has resulted in the smallest contribution of observations received at headquarters in many months, perhaps in years. Two observers each have reported from South Africa, Australia, Mexico, Canada, and one from Japan, with 39 observers in this country. The number of foreign con-

tributions is not likely to increase in the near future, so it is hoped that American observers will take upon themselves the responsibility for making more observations of more variable stars, so that the long-established completeness of the light curves will not suffer.

Observer	Var.	Obs.	Observer	Var.	Obs.
Ball, J.	6	13	Koutz	15	15
Blunck	8	11	Livingston	2	6
Bouton	34	49	Mason	17	23
Cameron	8	8	Maupome	43	49
Cave	2	4	McPherson	23	23
Cilley	54	155	Nadeau	5	6
Cousins	34	50	Parker	10	10
Dafter	7	16	Parks	24	38
Diedrich	5	5	Peltier	53	94
Escalante	101	175	Prinslow	4	5
Fernald	90	158	Purdy	8	8
Franklin	17	26	Roe	1	1
Griffin	52	52	Rosebrugh	15	38
Guthrie	1	1	Saxon	2	6
Hamilton	5	5	Schoenke	5	16
Harris	11	11	Sill	17	17
Hartmann	142	173	Smith, F. P.	5	10
Holmes	6	6	Stahr	3	3
Holt	138	299	Taulman	24	41
Howarth	18	21	Topham	10	10
Irland	10	12	Vohman	3	3
Jones	53	136	Webb	14	14
Kearons	61	102	Yamasaki	43	47
Kelly	12	17			
deKock	52	219	48	Totals	2197

February 14, 1941.

Comet Notes

By G. VAN BIESBROECK

The year 1941 has started out with two new comets discovered in the first month, not to mention a recovery of Periodic Comet Encke, all of which occurred within a week's time.

Comet 1941 *a* (Friend). Mr. Clarence L. Friend using a 5-inch Mellish refractor at his private observatory at Escondido, California, found this rather inconspicuous object moving in the constellation of Lacerta on January 17. This is the second new comet found by this amateur astronomer who has already Comet 1939 *n* to his credit. When first observed here on January 19, I estimated the total magnitude as 10. The comet showed a very diffuse nucleus expanding into a broad fan-shaped tail about 3′ in extent in position angle 230°. The comet was immediately measured in many observatories and soon a preliminary orbit was computed showing that the conditions of visibility were improving. Backwards computation made it possible to determine a position from a pre-discovery image on a Harvard sky patrol plate taken on December 31, 1940. A number of preliminary orbits have been computed from short arcs but with the help of the pre-discovery position, Messers K. Guthe and R. N. Thomas of the Harvard Observatory have computed these more accurate elements:

Perihelion passage	1941 Jan. 20.633
Node to perihelion	132°35'9
Longitude of node	329 2.9
Inclination	26 36.5
Perihelion distance	0.94285

giving the ephemeris:

1941	α h m	δ ° ′	—Distance from— Earth	Sun	Magn.
Feb. 11	2 19.4	+61 2	0.186	1.015	8.5
15	4 26.3	56 32	.163	1.043	8.3
19	6 6.6	43 45	.157	1.074	8.4
23	7 6.6	+28 16	0.171	1.108	8.7

This shows that on February 18 the comet approaches the earth to within 0.156 astronomical units. Its apparent motion is correspondingly fast and the maximum of brightness is reached at that time. Towards the end of February the comet moves rapidly southward while fading considerably in brightness.

Comet 1941 *b* (Periodic Encke). On a pair of plates exposed by the writer at the 24-inch reflector of the Yerkes Observatory on January 19, this expected object was recognized as a tiny round coma of magnitude 17. It was recorded again on January 20 and 25, the diameter of the coma being about 15″. The position is remarkably close, within 3′ of the prediction made by the late A. C. D. Crommelin and published in the *Handbook of the British Astronomical Association 1941*. While gaining in brightness, the comet now moves farther into the evening sky and will soon be too close to the sun, but in May and June it will be visible as a morning object, but southern observers will be best situated for following it. This is the fortieth reapparition of this famous object, the observations of which started as far back as 1786 when it was discovered by Mechain in France.

Comet Paraskevopoulos February 9, 1941

Comet 1941 *c* (Paraskevopoulos). A radiogram from Dr. John Paraskevopoulos, who is in charge of the Boyden Station of the Harvard Observatory, Bloemfontein, South Africa, reported the discovery of this bright comet:

1941 Jan. 23 Right ascension $16^h 48^m$ Declination —46°
Magnitude 3.5 Tail 5° in length

As usual, such an object is found independently by several observers: At the Cordoba Observatory (Argentina) it was seen by the three observers M. Dartayet, J. Bobone, and Cecilio on January 24; at Santiago (Chile) it was found by R. Grandon who gave already an accurate position for January 23 and called the magnitude 2; photographic discovery was reported by E. Ronbaud and A. Pochintesta at Montevideo (Uruguay) on January 24, while J. Jackson, at the Cape of Good Hope, in communicating a first set of elements, calls the object "Comet de Kock" suggesting another independent discovery in South Africa. The comet moved rapidly south-eastward and made a fine appearance for southern observers, who must have had the unusual opportunity of seeing simultaneously two bright comets visible with the naked eye, the second one being Cunningham's comet whose rapid southern flight had evaded our sky in the early part of January. Preliminary orbits were computed as follows from the early observations on

COMET 1941 *c*:

Computers	L. E. Cunningham 1941	A. D. Maxwell 1941	Wood & Jackson 1941
Perihelion passage	Jan. 27.682	Jan. 27.653	Jan. 27.779
Node to perihelion	268° 30′	268° 39′	268° 26′
Longitude of node	42 2	42 15	41 50
Inclination	168 11	168 12	168 8
Perihelion distance	0.7899	0.7900	0.7894

The following ephemeris deduced from the first set of elements describes the course of the comet in the first half of February:

1941	α h m	δ °	Light
Feb. 4	0 39	—25.4	1.3
6	1 1	17.8	0.9
8	16	12.3	.64
10	26	8.2	.46
12	33	5.1	.35
14	1 39	— 2.7	0.27

Several reports have already come from observers located in the southern part of the country who caught sight of the comet in the first days of February. Mr. C. L. Friend, discoverer of 1941 *a*, saw the newcomer on the evening of February 2, estimated the length of the tail "over 20°" and the brightness almost as great as that of Halley's Comet! Cloudy weather prevented observations at Williams Bay until the evening of February 4, when I estimated the magnitude as 3 with the naked eye, but the moon was already interfering and the tail was not conspicuous anymore. The figure gives an idea of the appearance of the object on February 9. It is enlarged from a 4-minute exposure made with the 24-inch refractor on a sky strongly illuminated by the moon. The already over-exposed head does not show the small stellar nucleus out of which streams the material forming the head. The tail with its hollow core could not be seen over more than 2° on the bright sky. As indicated by the ephemeris the magnitude will drop rapidly from now on, but the object will remain for some time in good observing conditions in the constellation of Cetus.

Another independent discoverer of comet 1941 *c* is Mr. R. A. McIntosh, Auckland, New Zealand, who found it on January 24; he determined a rough position and the daily motion at his private observatory. In a letter to the Director of the Harvard College Observatory he gives the following description for that date: Magnitude 3.3. Star-like nucleus. Coma 1′ in diameter, brighter at front showing trace of sunward jet. Tail about 7 degrees long in position angle 60°, parabolic in form but with the southern side full length and the northern side only one degree long.

There is not much likelihood that the comets mentioned in the previous months will be observed further. Both COMET 1940 *e* (OKABAYASI) and PERIODIC COMET 1940 *b* (WHIPPLE) are now too faint for most telescopes.

Williams Bay Wisconsin, February 11, 1941.

Notes from Amateurs

The Minneapolis Amateur Astronomy Club

This section of the country has always seemed to be woefully lax in its interest toward astronomy. Probably the weather has been somewhat responsible. We seldom seem to suffer for lack of clouds, especially on a night when we have planned a field trip or "star-gazing party."

Nevertheless, this past year our association has gone a long way to create interest in this field. Minneapolis is blessed with a number of parks on high ground having an unobstructed view of the heavens. During the Aquatennial last summer we took it upon ourselves to give the public some "star-gazing parties," fashioned after the now famous Cleveland events. Although we cannot boast of audiences such as they entertained, we did accommodate several thousand enthusiasts. The interest was such that the Park Board gladly backed us in a series of weekly parties last fall when Jupiter and Saturn were first visible in the evening sky. These events met with such a response that we will endeavor to continue this practice during this coming spring and summer.

Our drawback has been a lack of speakers during the winter months. We think we have overcome this, however, by assigning a variety of lectures to the more able speakers in our membership, giving them several months for research on the various subjects. In this way the speaker himself benefits a thousandfold, while the other members are given an excellent lecture without aid from outside the club. Lectures are held the third Wednesday in the month, while on the other Wednesdays the telescope group meets to grind mirrors and discuss their hobby. The meeting place is the Minneapolis Library Museum.

The highlight of the year is our annual visit to the Goodsell Observatory at Carleton College at Northfield, Minnesota. Thus far we have never hit upon a clear night, but the trip through the building, with its many fascinating instruments and photographs, makes the visit always worthwhile. We hope that the fates will be kind on our next trip, so that we can get a good look through the fine refractor at some of the wonders of the heavens.

February 15, 1941. WENSELL FRANTZICH.

Amateur Astronomers Association of Pittsburgh

The officers of this Association for the current year are: F. M. Garland, President, H. C. Kyle, Vice President, L. N. Schoenig, Secretary, W. A. MacCalla, Treasurer.

A schedule of regular meetings up to and including June has been prepared and is given below. These meetings will be held in the Club Room, Buhl Planetarium, North Side, Pittsburgh, Pa.

Friday, Jan. 10, 8:00-9:00 P.M.—Regular Business Meeting; 9:00 P.M.—Lecture: "Light, the Star Reporter of the Universe," by Dr. George E. Davis, Associate Professor of Physics, Duquesne University.

Friday, Feb. 14, 8:00-8:30 P.M.—Regular Business Meeting; 8:30-9:30 P.M.—Lecture, "Infra-Red Rays, Their Use in Science and Industry" and "Aluminized Surfaces," by Dr. C. E. Leberknight, Assistant Professor of Physics, Carnegie Institute of Technology.

Friday, March 14, 8:00-8:30 P.M.—Regular Business Meeting; 8:30-9:30 P.M.—Lecture: "The Planet, Earth," by Dr. Daniel A. Busch, Department of Geology, University of Pittsburgh.

Friday, April 11, 8:00-8:30 P.M.—Regular Business Meeting; 8:30-9:30 P.M.—Lecture: "Reminiscences," by Dr. Keivin Burns, Assistant Director, Allegheny Observatory, University of Pittsburgh.

Friday, May 9, 7:45-8:15 P.M.—Regular Business Meeting; 8:15-9:00 P.M.—Lecture: "Our Expanding Universe," by Dr. Frank C. Jordan, Director, Allegheny Observatory, University of Pittsburgh; 9:00-9:45 P.M.—"Old Timers' Night," with our first Secretary, none other than Leo J. Scanlon, running the show!

Friday, June 13, 8:00-8:30 P.M.—Regular Business Meeting; 8:30-9:30 P.M.—"Junior Program." This fateful hour is in the hands of junior members. Larry Kampel, sponsor of so many young fellows, has given his kindly advice to these boys, and the program will be good!

An elementary Astronomy study course will be conducted in the Club Room of the Buhl Planetarium. It will be under the direction of Clarence A. Atwell. The schedule of meetings follows:

Friday, Jan. 10, 7:00 P.M.—Our Star and its Behavior, Mrs. E. S. Wiegle.
Tuesday, Jan. 21, 8:00 P.M.—Elem. Math. of Astron., C. T. Sloan.
Friday, Feb. 14, 7:00 P.M.—The Eight Other Planets, C. A. Atwell.
Tuesday, Feb. 25, 8:00 P.M.—Elem. Physics of Astronomy, C. T. Sloan.
Friday, Mar. 14, 7:00 P.M.—Asteroids, Comets, and Meteors, Z. Daniel.
Tuesday, Mar. 25, 8:00 P.M.—Elem. Phys. of Astron., C. T. Sloan.
Friday, Apr. 11, 7:00 P.M.—Stars, Stars and Stars, Leo Scanlon.
Tuesday, April 22, 8:00 P.M.—Elem. Phys. of Astron., C. T. Sloan.
Friday, May 9, 8:15 P.M.—Our Expanding Universe, Dr .F. C. Jordan.
Tuesday, May 20, 8:00 P.M.—Quiz Program, C. A. Atwell.

At our regular Annual Meeting in May, election of officers will be held to cover the period June, 1941, to May, 1942.

FRED M. GARLAND, *President.*

1006 Davis Ave., Pittsburgh, Pa.

Detroit Astronomical Society

This society meets at Wayne University, the second Sunday afternoon of each month, during ten months of each year. Field meetings are also arranged when opportunity arises. At the close of 1940, the total membership consisted of fifty-one, seven of whom had joined during the past year. A lending library of books pertaining to astronomy was started and has proved to be most helpful and popular. Mr. C. W. Spain, treasurer, took charge of the books.

The January meeting is devoted annually to business reports and election of officers. An executive meeting was also held during the month to arrange the program of lectures which resulted as follows in the year 1940:

February — Dr. W. Carl Rufus, University of Michigan, "Tektites."
March — Dr. Carl E. Dutton, Geologist, Wayne University, "The Interior of the Earth."
April — Dr. E. R. Phelps, Wayne University, "The History of the Calendar."
May — Dr. Donald C. MacLachlan, Wayne Univ. geologist, "Continental Glaciation".
June — A group visit to the observatory, Ann Arbor, by kind invitation of Professor Heber D. Curtis, Director.
September — Colored motion picture films by Mr. Claude B. Carpenter, President; also reels taken at the meetings of the A.A.V.S.O.
October — Dr. E. R. Phelps, Wayne University, "The Spectroscope and its Uses in Astronomy."
November — A group visit to Cranbrook Institute of Science, when Dr. Robert T. Halt, Director, entertained the Detroit Astronomical Society and also the Northwest Amateur Astronomical Society of Detroit. Dr. Orren Mohler showed the latest Sun Films from Lake Angelus Observatory.

November — Dr. Jesse Ormondroyd, University of Michigan talked on the "Mounting of the 200-inch."
December — Dr. Allan D. Maxwell, University of Michigan, "Comets."

MRS. MARGARET BACK, *Secretary.*
168 Vendome Road, Grosse Point Farms, Michigan.

The Cleveland Astronomical Society

The new Warner Auditorium of the Warner and Swasey Observatory was the place of the meeting held on January 31. The speaker, Dr. S. W. McCuskey, used the subject "The Sun a Stellar Laboratory." He developed the lecture in a systematic and clear manner holding the attention of a large audience. It was apparent to many of us younger amateurs that new concepts have superceded those of our college textbooks in regard to the Sun.

Election of officers for the coming year and Secretary's report followed. The new officers include Dr. J. J. Nassau, observatory director, president; James Russell, vice president; Mrs. Royce Parkin, secretary-treasurer, and Don H. Johnston, recording secretary. To direct the group's recently acquired library, Miss Helen Focke was named librarian. Nine members of the executive board elected include Dr. O. L. Dustheimer, Robert Ingle, Dr. S. W. McCuskey, Royce Parkin, A. G. Stucky, H. C. Stuessy, S. K. Towson, C. M. Yoder, and Dr. David Dietz. Dates for meetings of the Telescope-Making section are as follows: February 7, 6:30 to 8:00 P.M., February 17, 7:30 to 9:00 P.M., March 7, 6:30 to 8:00 P.M., March 31, 7:30 to 9:00 P.M., April 11, 6:30 to 8:00 P.M., April 21, 7:30 to 9:00 P.M., May 9, 6:30 to 8:00 P.M., and June 6, 6:30 to 8:00 P.M. This work will be under the direction of James Russell, a talented optical worker and vice-president of the society. All of the meetings will be held at the Warner and Swasey Observatory, with the exception of those held on February 17, March 31, and April 21. These meetings will be held at the Burrell Observatory, Berea, Ohio.

DON H. JOHNSTON.
Euclid Beach Park, Cleveland, Ohio.

General Notes

Dr. Frank C. Jordan, who was associated with the Allegheny Observatory since 1908, as director since 1930, and who was treasurer of the American Astronomical Society, died on Saturday, February 15, as a result of an unusual accident. Dr. Jordan had gone to the basement to attend to the furnace. While there an explosion of gas enveloped him in flames and set fire to the surroundings so that it was impossible for him to escape. Mrs. Jordan, who had been ill for some weeks, was on the second floor. Noticing the smoke pouring into her room, she went to the window to call for help. She fainted while waiting to be rescued and died before she could be removed from the building. The Astronomical fraternity thus loses two most estimable people.

Dr. Dirk Brouwer, at present associate professor of astronomy in Yale University, has been elected to a full professorship, and to succeed Dr. Frank Schlesinger as director of the Yale University Observatory, upon his retirement in June, 1941.

Dr. Brouwer was born in Holland in 1902. He received his Ph.D. at Leiden

in 1927 under Dr. de Sitter, specializing in celestial mechanics. He came to this country in 1927 as a fellow of the International Education Board, studying at Yale and also at the University of California. The next year he was appointed assistant to E. W. Brown at Yale, and upon Professor Brown's retirement in 1932 became instructor in astronomy at Yale, and in a sense successor to Professor Brown.

Dr. DeLisle Stewart, organizer of the Cincinnati Astronomical Society and its president since 1910, director of the observatory of the Cincinnati Astronomical Society since 1936, died at his home in Cincinnati on Friday, February 7, 1941. Dr. Stewart received the degrees of B.L. and Ph.D. from Carleton College and later spent six years in work at the Harvard Astronomical station in Arequipa, Peru. In recent years he has devoted his efforts to the promotion of the interest in astronomy through the society of which he was president.

Mr. Paul Ledoux arrived at the Yerkes Observatory on December 28, 1940, in order to begin his work in theoretical astrophysics under the direction of Professor Chandrasekhar. He is the recipient of a fellowship from the Belgian-American Educational Foundation of New York. Mr. Ledoux was an assistant at the Institute of Astrophysics of the University of Liege where he worked under Professor P. Swings. He was engaged in astrophysical work with Professor Rosseland at Oslo from March, 1939, to May, 1940, and published articles on stratified atmospheres, etc. He was in Oslo at the time of the invasion of Norway. Having received permission to return to Belgium, he started by way of Sweden but was informed upon his arrival in Stockholm that Belgium had been invaded by the Germans. For several months he worked at Saltsjöbaden under Lindblad and Öhman. Having received the confirmation of his appointment as Fellow of the Belgian-American Educational Foundation, he and Mrs. Ledoux traveled by plane to Riga and to Moscow, thence across Siberia to Vladivostok by train and by ship to Yokohama and Seattle.

The Rittenhouse Astronomical Society, at its monthly meeting on Friday, February 14, was entertained by a report on "The National Geographic Society 1940 Eclipse Expedition to Brazil," given by Dr. C. C. Kiess, Physicist, U. S. Bureau of Standards.

The Royal Astronomical Society of Canada has elected Dr. Frank S. Hogg, assistant professor of astronomy in the University of Toronto and a member of the staff of the David Dunlap Observatory, as president for 1941. He succeeds Dr. J. A. Pearce, acting head astronomer of the Dominion Astrophysical Observatory, Victoria, B. C., who has been president for two years. (*Science*, January 31, 1941)

The Bruce Gold Medal of the Astronomical Society of the Pacific has been awarded to Dr. Joel Stebbins, director of the Washburn Observatory, Madison, Wisconsin. At the annual meeting of the society, held in San Francisco on January 25, Professor C. D. Shane of the department of astronomy of the University of California at Berkeley, in his address as retiring president, gave an account of Dr. Stebbins' distinguished services to astronomy. At the same meeting Dr. A. S. King of the Mount Wilson Observatory was elected president of the society for the year 1941. (*Science*, January 31, 1941)